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Comments from the Side Lines*

By ROBERT G. AITKEN

At midnight, on June 30, 1935, after completing a set of measures of the binary star A 88, I turned away from the 36-inch refractor, closed the door to the dome, and simultaneously closed my forty years of active service at the Lick Observatory. That means that I am now an old man and that if, in my address on this occasion, I were to attempt a complete analysis of some phase of the work in which I specialized during my active years, or of some general problem of current interest, I should at once lay myself open to a double barrage of criticism. My liberal minded auditors would think me too conservative, but would add "What else could you expect from such an old fellow?", and my conservative friends would shake their heads over any liberal statements, with the comment, "The poor old fellow is losing his mind!"

An escape from this embarrassing dilemma might be found in reminiscence, and, since it has been my good fortune to meet personally or to correspond with nearly all the better known astronomers of the past fifty years, I have ample material. But it has been said that reminiscence is the last resort of a man who can only look backward; and if I cannot say that I can look far forward, I can at least still look around me. I have therefore chosen rather to risk the criticism and to offer you, not indeed a scholarly disputation, but some "Comments from the Side Lines," where I have been standing or sitting leisurely for the past five years, viewing with the liveliest interest the progress that you and the other active workers in our science have been making.

Since I am simply commenting, I am clearly at liberty to be as discursive as I please, touching lightly upon this topic or upon that, whether they are related or not, without necessarily developing any one of them very fully, and passing over many quite as important as those on which I touch. It is even open to me to indulge in a bit of reminiscence when it helps to bring out some point I wish to make.

My good friend, the late Sir Frank Dyson, used always to insist that it was the duty of observatories to get observations. I agree with him, and the statement is as true today as it was the first time Sir Frank made it. It *is* the first and foremost duty of the staff of an observatory, not to theorize or speculate, but to get observations; to find out what has happened and is happening in the universe at large and where and when,

*Address of the Retiring President of the American Astronomical Society, delivered at the Wellesley College meeting of the Society, September 13, 1940.

and to make this information as precise and complete as possible. It is only when we have a sound and extensive collection of such data that we are in position to draw great generalizations, like the mass-luminosity relationship, for example, that will not only serve to correlate our observations but also give us a basis for prediction and a guide for further research.

Holding these views and having all my life been an observational astronomer, it is natural that my first comments should relate to telescopes and their auxiliary equipment. When I entered upon my professional career in 1895 the typical telescope was the refractor and it was the ambition of every observatory to secure as large a one as possible. The 36-inch Lick refractor, "superior to and more powerful than any telescope yet made," to quote James Lick's specifications, had been put into active service only seven years before and the 40-inch Yerkes refractor was dedicated about a year later. Quotations for one of 45 inches aperture were made as late as 1897,[1] but, though no one realized it at the time, the refractor had reached its maximum in the 40-inch.

Long before that great telescope was dedicated in October, 1896, the silver-on-glass mirror was well along its upward way. Men like Isaac Roberts and A. A. Common had used 20- and 36-inch reflecting telescopes with excellent success for a number of years and the story of the Crossley reflector, its donation to the Lick Observatory in 1895, and Keeler's brilliant demonstration of its great powers in the all-too-brief time he had to use it is known to all. Nor had Hale overlooked the promise that lay in further development of the reflector for even before he planned for the observatory to house the great Yerkes refractor, he had made provision for facilities for the construction, by Ritchey, of a 60-inch mirror.

Of the later history of reflecting telescopes as they have grown steadily in aperture with corresponding space-penetrating and resolving power, I need say little. With you, I have been thrilled with the marvelous revelations they have brought of the content and structure of our own stellar system and the new conception they have given us of the vastness of the universe. With you I have rejoiced in the recent installation of the 82-inch McDonald reflector and have watched with deepest interest the gradual approach to completion of the great 200-inch reflector on Palomar Mountain. I look forward eagerly to seeing it in action while I am still in the early years of the "side line" or Emeritus stage of my career.

Should we, for such part of future time as we have the right to envisage, accept the 200-inch as the maximum development of instruments of this type or should we look forward to the construction of a 300-inch, or larger, reflector? This is a question that is, I think, fairly open to

[1] The comparative figures may be of interest. The 36-inch telescope, lens and mounting, cost $92,000.00; the 40-inch, $121,000.00; the quotation for a 45-inch telescope was $145,000.00.

debate. The possibility of building such a supergiant may be taken for granted. The glassmakers are agreed that a disk of glass of any required dimensions can be successfully cast, the opticians are willing to undertake figuring it, the engineers, to provide a suitable mounting.

You will, of course, say that under present world conditions and those likely to prevail in the near future it is highly improbable that funds will become available for such expensive luxuries as great reflecting telescopes, and I shall fully agree with you. But I am not thinking of appropriations now; I am thinking solely of what will most effectively further the advance of astronomy and increase our knowledge of the universe.

Marvelous as are their powers and vastly as they have enlarged the volume of space brought within range of our investigations, the great reflectors are by their very nature adapted chiefly to the intensive and large scale study of individual objects, or at most of the objects within a very limited angular field of view, and to record the existence of extremely distant or faint objects. There are plenty of objects and problems enough relating to them now in view that can only be investigated by telescopes of this type to keep all the great reflectors we have, or see any prospect of securing, fully occupied for many years to come. And the desirability of building at least one supergiant will unquestionably come constantly more to the fore after the 200-inch comes into general use. If donors, either generous individuals or great institutions, can be found to provide funds for 80- or 100-inch reflectors, or one of 300 inches aperture, astronomers will certainly gratefully accept the responsibility of operating them.

But, on the other hand, the solutions of some of the most urgent present day problems in astronomy, problems relating to the structure and rotation of our galaxy, for example, and the relation of our galaxy to the others comprising the greater universe, require the collection of great quantities of data for statistical studies of the magnitudes, positions, motions, color indices, spectral classes of faint stars. Powerful telescopes of the Schmidt type or star-cameras of the Ross type that will record sharp images of all stars and nebulae to the 19th magnitude or fainter over a sky area six degrees or more square on a single plate are the instruments we need to give us such data, not great reflecting telescopes.

It was because I felt this need that I was so happy to be instrumental in securing the grant, in 1934, from the Carnegie Corporation of New York for the Ross star-camera now nearing completion at the Lick Observatory. When that instrument and the 48-inch Schmidt telescope now being erected on Palomar Mountain, and other instruments like them, have been in use for a few years, a comparative study to determine the relative advantages of the two types for the investigation of various problems will be highly interesting.

Instruments of both types will evidently supplement most usefully the

work of the great reflectors by singling out, among the myriads of ordinary faint stars, the relatively few that for various reasons demand more detailed examination; and both will serve equally well for star counts and for studies of the distribution of variable stars or faint star clusters or faint galactic and extra-galactic nebulae. But it may well be that one instrument will prove to be the better for the investigation of small proper motions, let us say, and the other for, say, photometric measures. When the possibilities of both instruments have been thoroughly investigated, it will be incumbent upon their fortunate possessors to plan their observing programs, by mutual agreement, in such manner as to secure maximum returns with a minimum of unnecessary, and therefore wasteful duplication.

All of the telescopes to which I have referred have been built to meet the astronomer's constant demand for more light; but too much light may sometimes be as baffling to our researches as too little. Thus, until 1869, we were compelled to wait for the occasional minutes when the moon kindly cut out the light from the sun's photosphere to study even the solar prominences and the lower layers of the sun's atmosphere in general. Now, thanks to the spectrograph, the spectroheliograph, the spectrohelioscope, and the spectroheliokinematograph, the chromosphere and the prominences, their spectral characteristics, and their ever-changing structure can be studied and recorded whenever the sun shines, and Lyot's coronagraph and Skellett's coronavisor have brought even the inner corona within range of daily observation.

I mention these well-known facts mainly to lead up to my expression of heartiest congratulations to the McMath-Hulbert Observatory upon the installation of the new tower telescope and its powerful equipment at Lake Angelus for the extension of the remarkable work that has been and is being done there and to the Harvard Observatory on the erection of a Lyot-type coronagraph at a high altitude station in the Rocky Mountains of Colorado. The day when we can dispense entirely with the romantic but costly and oft-times futile eclipse expeditions to remote corners of the earth is almost but not quite at hand;—not quite, for the outer corona still eludes us except when the sun is totally eclipsed.

Tower telescopes which have been or could be equipped with apparatus similar to that used at the McMath-Hulbert Observatory already exist at stations well distributed in longitude. It would be vastly to the advantage of astronomy if a Lyot coronagraph could be installed at a high-altitude station in the eastern hemisphere, in India, for instance, so that the corona, as well as the prominences and chromosphere might be kept under observation throughout the 24 hours of the day. We have had some rather confident pronouncements in recent years on the origin and destiny of the sun and the solar system, which have been interesting and not altogether implausible, but it would not be amiss to collect a lot of additional information on what is really happening from day to day upon the sun to check these speculations.

That "invisible glass" will be used for the lenses of the Harvard coronagraph illustrates once again the astronomer's indebtedness to the technologist. Technological advances, which the astronomer has been prompt to adapt to his own purpose have not only made possible his great telescopes with mountings as massive as the turret of a battleship working with the precision and delicacy of a fine watch, but have also given him the modern dry plate, with its extraordinary range and sensitivity, the photoelectric cell and the multitude of other accessory instruments which he attaches to his telescope or uses in the laboratory to study the images produced by his great lenses and mirrors. The contrast between the auxiliary equipment at the disposal of the modern astronomer and that available when I went to the Lick Observatory in 1895 is almost as great as the contrast in modes of communication and transportation. The filar micrometer was then the chief auxiliary attachment to the 36-inch refractor though Holden and others had taken moon photographs by attaching the big photographic correcting lens, a visual spectroscope had been used to good advantage by Keeler, Campbell, and others, and Campbell was designing the first Bruce spectrograph.

(Parenthetically, let me say that when I began my survey of the northern sky to study the distribution of double stars, my only guide, aside from probability considerations, to proper limits to set in defining a physical pair was the motion that had been observed in the Σ, OΣ, and β pairs. Less than a score of trigonometric parallaxes had been determined with any reasonable approach to accuracy, and comparatively little was known even of the proper motions of the fainter stars. My limits were necessarily arbitrary, designed to include all pairs likely to show orbital motion within a few decades after discovery and all pairs that might be overlooked on the astrographic plates then being taken.)

That purely astrophysical research, based upon modern theories of atomic structure and utilizing modern equipment auxiliary to our great telescopes, should exercise a powerful attraction upon the mind of present day astronomers is both natural and right. I, too, rejoice in every new advance made possible by the sensitive photographic films, the spectrographs, photoelectric photometers, and other equipment now available and I am persuaded that equipment even more effective in such research will continue to come into use.

At the same time, I cannot help regretting that, except for the determination of radial velocities, so little attention, relatively, is given to astrometric work. The good old micrometer, I believe, is still capable of giving results of prime importance to astronomy and we still urgently need systematic measures of close double stars, work for which the micrometer is still the instrument *par excellence*. We need greatly to increase the number of double star orbits, to study the motions in these systems and gain further light on their origin and evolution, and we need systematic measures not only of these pairs but also of those showing little or no relative motion for more complete investigations of dy-

namic parallaxes and stellar masses. I was happy to note that, in their excellent monograph with the title *Stellar Masses,* Russell and Miss Moore (Mrs. Charlotte Moore Sitterly) stress the need for measures of pairs of the latter type. Such slow moving objects are to be found, however, not only among the wider pairs which can best be measured photographically; many hundreds of them are to be found among pairs that can only be measured by the micrometer, and these are precisely the ones that should be measured now. The positions of many of the wider pairs are probably being recorded on photographs taken for other purposes and can be recovered from them.

Again, we shall never arrive at any satisfactory conclusions as to the extent and structure of our Milky Way system until we know far more accurately than we do today the distribution in area and depth of the clouds of impalpable material that so seriously affect star light passing through them by their general and selective absorption. To this end we require not only a photographic map of the entire sky in light of different wave-lengths, but also extensive and accurate photometric observations and measures of color index of single stars, star clusters, and nebulae and a thorough investigation of interstellar spectral lines.

It is hardly necessary to say that we also need all the observational data we can possibly secure that are likely to help us to a better understanding of the physical nature of a star and permit us to attempt to write the life history of a star as a luminous body. Thanks to laboratory investigations of the structure of the atom and to the theories based upon them, as well as to the ever-increasing accumulation of accurate analyses of stellar spectra, we are beginning to gain some insight into the sources of the radiant energy the stars are emitting at such prodigious rates and the processes by which that energy emission has been maintained throughout thousands of millions of years. But I am not yet willing to subscribe to the dictum that we *know* just why the sun is shining and why it will continue to shine for ages yet to come, even though modern theory apparently offers a reasonable explanation, on the basis of accepted principles and theory, of how this energy *might* be generated and maintained.

If all the stars were normal stars, if for example there were no red supergiants of incredibly low density and high luminosity and no feebly luminous white dwarfs of incredibly great density, the statement, "we know," might pass unchallenged. But until we have a theory that accounts fully for the presence of these and other exceptional objects in *the same stellar system with each other and with the normal stars* and also the occasional linkage of a normal star and a white dwarf of the same order of mass into a binary star system, as in the case of Sirius and its companion, affirmation of positive knowledge of why the stars shine and continue to shine seems premature.

In making this statement I am casting no reflections on the theories themselves. They are invaluable; they summarize the existing observa-

tional evidence and correlate it with accepted physical principles; they guide us in further investigations and constitute ever closer approximations to the truth. I am merely deprecating, mildly, the too confident "now we know" claims made by overly enthusiastic advocates of this or that theory.

Throughout these comments I have been dwelling upon the urgent need for securing ever more observational data; but I am not blind to the fact that at every active observatory such material is even now accumulating more rapidly than it can be properly examined, measured, and discussed by the observatory staff with reasonable promptness. The problem with which we are thus confronted is already a troublesome one and will become more so when Ross star cameras and Schmidt telescopes come into more active use. And it is aggravated by the fact, which is becoming increasingly evident, that the developed photographic plate grows old and deteriorates with increasing age even as does the astronomer himself.

A moratorium on observation, however, is not the way out of the difficulty. We need the observations and we need them now; they cannot be made *at this epoch* at a later time. No. We must find means of keeping more nearly abreast of our observational material and also of prolonging indefinitely the useful life of the exposed photographic plate. The latter is a purely technological problem and must be left to the technologists; the former, is a problem of administration and particularly of coöperation and must be solved by the astronomers themselves. It is fully as difficult as the technological problem but I do not question the ability of our astronomers to find a satisfactory solution. This does not mean that I have a solution to offer; it will take the best efforts of many minds to arrive at one that is satisfactory.

I do, however, want to say that I think the key to the solution lies in coöperation. Astronomers have long been noted for their spirit of coöperation and nearly every journal records the acknowledgment of some investigator for assistance given by the loan of spectrograms or photographs. Classic examples of the benefits we have derived in the past from coöperation on a larger scale are familiar to us all. In the future, I think, we must practice coöperation even more extensively, not only in such formulations of observing programs as I have already suggested for the possessors of Ross star-cameras and Schmidt telescopes but more particularly in the collaboration of observers with other competent men (and women) who are working at institutions where lack of instruments or poor observing conditions prohibit observations but where suitable measuring apparatus and other laboratory equipment are available or can be obtained.

The problem, as I have said, is not a simple one; many details will have to be worked out carefully. The rights and privileges of both parties to such a joint enterprise must be conserved; the original negatives or other observational material must be safeguarded; provision for

publication of results must be made. But these items, and others, are administrative matters that will not prove to be insuperable obstacles if the spirit of coöperation is really present.

I want now to draw attention to the rapid increase in numbers of enthusiastic amateur astronomers for I regard this as one of the most remarkable and significant developments in the recent history of astronomy in America. All over the country mirrors and lenses are being figured and mounted in ever greater number by amateurs ranging in experience and ability from school boys and girls to professional engineers, executives of great corporations, lawyers, doctors, and business men. Other instruments as well as telescopes—spectrographs, spectrohelioscopes, photometers—are being constructed and used, the full equipment of an amateur ranging all the way from a pair of field-glasses or a 3- or 4-inch mirror on a tripod mounting to the great observatory of the late Dr. Cook and the original McMath-Hulbert Observatory at Lake Angelus. All over the country, too, they have been organizing into clubs and societies to discuss problems of instrument construction and to plan observing programs, for they are eager to use the instruments they have constructed to observe the sun, the moon, the planets, and the comets and not a few are extending their researches to the stars and nebulae.

Improvements in telescope mountings, new instruments, new observing methods have been among the contributions made to astronomy by American amateurs in recent years. New comets and variable stars have been discovered by them, and the systematic observations of variable stars carried out by many of them under the auspices of the Harvard Observatory afford an admirable illustration of what can be accomplished by well organized coöperation. I was glad to note that a number of professional astronomers participated in the program of the Second National Convention of Amateur Astronomers held in Pittsburgh over the weekend following July 4, for we should all of us regard it as a high privilege to help our amateur associates in every possible way. We are already deeply indebted to them and I, for one, think we need not worry about the future of research astronomy in our country as long as the professional astronomers have the backing of so large and enthusiastic a body of amateurs.

Astronomy in our own country, I said, and this has been foremost in my thoughts throughout my remarks; but I cannot bring these random comments to a close without some reference to the plight of our honored colleagues in other lands. Of all the sciences, astronomy is the one least concerned with boundary lines of nation, race, or creed. The stars shine on all men alike; they make no distinctions; why should we? This is something we have long recognized and our International Astronomical Union was, in fact, organized to promote world-wide coöperation in astronomical research. Under present world conditions it can function hardly better than the League of Nations; the meetings scheduled for next year must be—not abandoned, we hope, but—deferred to some

future, happier day; observatory work has been sadly restricted, for the lenses and mirrors of great telescopes in England certainly, and, it is safe to say, at many, if not most, European continental observatories and some in Asia and Africa, have been removed from their mountings and stored in bombproof shelters. As for individual astronomers, some, like those at Warsaw, have been thrown into concentration camps, others have been deprived of their positions, and many, especially the younger men, have exchanged their peaceful researches for military service.

In my opinion it is incumbent upon us, in collaboration with those of our colleagues abroad whose work has as yet not been seriously interrupted, to see to it, first of all, that the framework of the International Astronomical Union is preserved, and that, as far as possible, the programs of the various committees are carried out as planned. We must also give thought to the individual astronomers who may find their way to this country; but this is part of a far larger problem involving the welfare of all professional men who are driven from home and that must be given over to some general organization like the American Association for the Advancement of Science, so far as scientific men are affected. The astronomers will want to do their part generously, but particular care must be exercised that we do nothing to place in jeopardy the careers of the young astronomers trained in our own universities and observatories.

I am standing on the side lines, as I remarked in the beginning, and I have found it a pleasant place to stand and one that affords a singularly interesting view of what is going on in the astronomical world; a view that is more enjoyable because of the absence of any sense of responsibility. Within the next few years a number of those who are now in positions where such responsibility still weighs upon them will join me and will, I hope, find the place as agreeable as I have. Good men will succeed them and the work will go on for, as Mr. Wendell Willkie reminded Mr. Franklin Delano Roosevelt, "No man is indispensable."

August 24, 1940.

Raymond Smith Dugan

By HENRY NORRIS RUSSELL

American astronomy—and variable star astronomy in particular—lost one of its best observers when Raymond Smith Dugan died on August 31, 1940.

He was born in the small Massachusetts town of Montague, on the edge of the Connecticut Valley in beautiful hill-country, upon May 30, 1878, and bore the marks of New England with him. Most of his ancestors were of old Yankee stock—indeed, his mother could count her descent from Miles Standish—but his paternal grandfather came from Ireland. His early schooling was of the sound type associated with the place and time, and he attended college near home at Amherst, where he received his A.B. degree in 1899.

His next six years were spent abroad, three as instructor in mathematics and astronomy at the Syrian Protestant College (now the American University) at Beirut, and the three following at Heidelberg in study under Max Wolf—for whom he had an affectionate and well-founded regard. During this time he took part in the search for asteroids characteristic of the Königstuhl Observatory, and discovered eighteen. In naming these (some of them after his return to America) he commemorated his Alma Mater and his adopted university in (516) Amherstia and (508) Princetonia; his birthplace in (535) Montague, his sister in (517) Edith, and his teacher, David Todd, in (511) Davida. The names of some of his other discoveries were given in a less serious mood—notably (518) Halawe, which immortalized a Syrian variety of sweetmeat, which he had much enjoyed while in the Near East. He received his Ph.D. degree in 1905, with a thesis entitled "Helligkeiten und mittlere Örter 359 Sternen der Plejaden-Gruppe," returned in the summer to this country, and was appointed instructor in astronomy at Princeton in 1905—remaining in the service of that University till his death—and beginning thirty-five years of unbroken friendship with the writer, who was called at the same time, to the same place, and with the same title.

At that time the research equipment of the Observatory consisted of the 23-inch equatorial—with an excellent objective by Alvan Clark, and a mounting by the same maker (whose fame does not rest on his mechanical constructions). The equipment for visual spectroscopy, with which C. A. Young had done such excellent work in earlier days, had been supplemented by a Pickering sliding-prism polarizing photometer—secured on the advice of W. Maxwell Reed, who was assistant professor of practical astronomy from 1901 to 1905. Dugan had at that time little or no experience in either field; but he realized the usefulness of an instrument which was then of the most modern type, and still remains unsurpassed in its particular field, and began a program of visual

photometric observation which he pursued with undiminished interest throughout his career.

Earlier than most observers, he had the insight to perceive that the heavy work involved in precise photometry could be most profitably expended upon such stars as possessed light curves which repeated themselves precisely, and could be discussed in detail, on the basis of well-established theory—that is, upon eclipsing variables.

Undaunted by the prospect of making ten thousand settings upon a single star, he decided at the start to secure precise light curves, accurately defined by observations covering every part of the period, for a few stars, rather than rougher results for many. The wisdom of this policy was doubted even by so great an astronomer as E. C. Pickering; but Dugan's method has not only been fully vindicated, by the success of his own work, but has become the standard practice of observers who have precise photometers to work with.

The derivation of the elements of these systems from their light curves was at that time no easy task—the direct methods now in use were developed seven years later—but he was no more disheartened by heavy computation than by laborious observation.

At that time the resources of the Observatory were small, and the members of its staff had to "do their own work" without benefit of computer or stenographer. His early publications dealing with RT Persei (1911) and Z Draconis (1912) represent an amount of single-handed labor which is by no means completely described by the statement that the first depends upon 904 and the second on 1149 observations, each the mean of 16 readings.

From the discussion of these stars, he showed that ellipticity of figure —previously recognized in the case of very close pairs like Beta Lyrae— was a general property of eclipsing variables, and discovered the "reflection" effect arising from the heating of the side of the companion which faces the smaller but hotter and brighter primary. He followed some of his stars—notably RT Persei,—year by year as long as he was able to observe, finding slow changes in their periods. A comprehensive study of such changes, made by the generous coöperation of the Harvard Observatory, and with the aid of its great collection of plates, was his last published work. In a few cases—notably Y Cygni—the changes in period can be accounted for by the rotation of the line of apsides in an eccentric orbit; but in other cases the primary and secondary minima show oscillations in the same phase, keeping equally spaced. In such systems the mean longitude is subject to changes of many degrees in amount, and of complicated character, requiring at least two or three periodic terms to represent it, if indeed it is periodic at all. These changes are so slow that, as he lamented whimsically a year or two ago, "an astronomer ought to live at least a hundred years to follow them up."

He was an excellent teacher, and inspired successively a long line of

graduate students with his interest in eclipsing variables. Of the nineteen "Contributions from the Princeton University Observatory" which have so far appeared, Dugan was author of twelve and joint-author of another, while four more, dealing with eclipsing variables, are the work of his students Pierce, Sitterly, McDiarmid, and Shapley. In 1937, when he took account of the record, he had made more than 300,000 photometric settings, and his students 200,000 more. The "Finding List for Observers of Eclipsing Variables" (*Princeton Contr.* 15, 1934) summarizes his critical assessment of work published to that date, and is still a very valuable guide. He had an important share in the preparation of the textbook on astronomy in which the writer and J. Q. Stewart participated. The high quality, as well as the volume, of his work, was widely recognized. He held a full professorship at Princeton from 1920, was elected a member of the American Philosophical Society, was a member of the Commission on Variable Stars of the International Astronomical Union for many years, and its Chairman from 1935. He took great interest in the American Astronomical Society, and was its secretary for nine years, being re-elected annually from 1927 to 1936, until he asked to be relieved from further service—whereupon the Society elected him vice-president.

On many occasions, when the writer was on leave, abroad or in California, Dugan was acting director at Princeton and showed excellent judgment and executive ability. For the rest of the time, he was a colleague in administration—not a subordinate—and did his full share, unobtrusively and with the best grace.

During the War he taught navigation to many students who desired to qualify for commissions in the Navy. They were so keen that they went, at their own expense, on a passenger steamer from New York to Florida and back. The officers fixed up a special bridge for the group, and probably no ship ever had her position fixed by a greater number of sights.

Of his personal characteristics, those which stand out in memory are his courage—of which more later—and his unfailing humor. His inherited Irish wit and the Yankee sense of incongruity, combined into a delightful blend, which crops out unexpectedly in his reports of meetings of the American Astronomical Society, and finds its best published expression in his account of the tribulations of an observer at the old Halsted Observatory.*

A student at Princeton, who was evidently of a literary mind, once handed in an excellent examination, containing incidentally an immortal sentence "Telescopes are of two kinds,—refractory and reflective." Observers will probably agree that all telescopes are more or less refractory, and they will read his account with sympathetic chuckles. Those who worked in the old dome will have deeper feelings. For example, "The

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shutter was pulled up by a rope which passed over a large wooden wheel high on the dome, and under a wheel below the floor. The astronomer turned on the power, coaxed the motor to full speed without having the belts fly off, opened a trap door in the floor, lowered the rope with both hands, and skillfully allowed a prong on the spinning wheel to hoop the rope into the channel. Then, with an agile leap across the hole, he took up on the slack with a snatch block. It took two years to learn the trick." Two years is a large estimate, according to the writer's memories—but they recall vividly how dirty the rope got from trailing on the floor!

His story closes with a description of the New Observatory, with its electric controls and rising floor, and of the comfort in store for the observer. Alas, he was not to enjoy this long. In 1935 he was increasingly disturbed by arthritis, which increased, despite all attempts to check it, to a degree which put an end to his night-work. Though often subject to severe pain, he continued quietly with his work—developing an effective technique for teaching students from an arm-chair when he was no longer able to stand at the blackboard, and continuing his research. The mass of observations, which he had already accumulated provided material for good light-curves of some stars—one of which he left practically ready for publication—and he completed a discussion of variations in period of a number of eclipsing systems, based largely on observations made on the plates of the great Harvard collection by Miss Frances Wright (*Princeton Contr.* 19, 1939).

Finally the long strain of his illness wore down his rugged constitution. Blood transfusions failed to check the mischief, and he died in the Bryn Mawr Hospital, whither he had gone for special treatment. His courage was with him to the last, and, on the morning before his death, he talked with his characteristic humor. His widow and two adopted children survive him.

He was buried in the Princeton cemetery, not far from many great men of earlier days. The simple and appropriate service was conducted by the pastor of the Presbyterian church which he attended.

Variable-star astronomy has lost one of its most experienced and wisest representatives; Princeton has lost an able and devoted professor; and astronomers in this and other lands mourn the departure of a valued friend.

For more than thirty years, Dugan and I were close associates. For a great part of that time there were but two members of our department of astronomy, so that any vote had to be either unanimous or a tie. So far as I recall the question how such a tie might be broken never arose.

PRINCETON, SEPTEMBER 28, 1940.

Elihu Thomson: His Interest in Astronomy*

By HARLAN TRUE STETSON

Everyone who came in contact with Dr. Elihu Thomson was impressed with a man of rare ingenuity and of exceptionally broad interests. He combined the practical outlook of the engineer with a fruitful imagination that invaded even the starry universe. His interest in astronomy, however, was not that of the bystander but of one who, from a vast store of knowledge, contributed again and again to this sideline of his engineering profession.

With a combination of mechanical skill, inventive genius, and a love for astronomy, it is not surprising that we find him in 1899 determined to construct a telescope for his own private observatory. Not content with designing the mechanical parts for the mounting, he set for himself the difficult task of making the optical parts for his 10-inch refractor. Today many amateurs derive profit and pleasure from grinding in their own workshops mirrors for reflecting telescopes. The task of creating a single concave surface for a reflecting telescope, however, though not an easy one, is relatively simple compared with the making of an achromatic objective where glasses of different densities must be used, refractive indices measured, and color corrections allowed.

Because of the patience and characteristic enthusiasm of this inventor, he successfully brought to completion a Steinheil objective of a focal length of 135 inches and a clear aperture of 10 inches. In an original manuscript found in his files under date of December 11, 1930, he states that "The performance of the lens was as good as could be expected. It resolves double stars down to .5 of a second separation and this is about the theoretical limit of a 10-inch aperture. . . . The outstanding secondary spectrum is a minimum for the glasses used and the lens shows stars of small magnitude with a single interference ring around the image."

Professor Thomson's greatest contribution towards the instrumental side of astronomy came with his development of the process for creating disks of fused quartz that would be suitable for use as the optical mirrors of reflecting telescopes. With the advent of the modern era of great telescopes marked by the completion of the 100-inch Hooker Telescope of the Mount Wilson Observatory, it became increasingly evident that the change in the optical surface of the mirror accompanying changes in temperature seriously limited the useful hours of such giant instruments.

Much experimenting in the Thomson Research Laboratory of the General Electric Company was directed to perfecting a process for producing quartz disks to overcome this difficulty. Dr. Thomson not only

*Presented at American Philosophical Society, Philadelphia, February 16, 1939.

was quick to perceive the merits of quartz, or fused silica, over the ordinary borosilicate crown glass, but his imagination envisaged larger and larger telescopes whose synthetic optical parts would be constructed in this way. He describes in a paper read before this Society in November, 1929, the experiments by which he convinced himself of both the feasibility and the desirability of constructing astronomical mirrors of quartz.

At the request of Dr. George Ellery Hale, he subsequently made for the Mount Wilson Observatory mirrors of sufficient size for the telescope in the solar tower of that observatory, thereby greatly improving the sun's image over that resulting from the previously used glass mirrors whose rise in temperature with the exposure to sunlight often impaired the optical definition. It is little wonder that, when plans matured for a 200-inch telescope for the California Institute of Technology, Dr. Thomson's enthusiasm led to the attempt to manufacture the huge disk of fused quartz at the laboratories of the General Electric Company.

In the early stages electric furnaces had to be constructed capable of maintaining temperatures of more than 3000° F. for the melting of silica. He first melted a mass of good clean quartz sand in a circular mould obtaining thereby a vast slab of fused quartz. It was immaterial that this disk or slab was full of tiny bubbles. The bubbles tended to make the aggregate mass lighter but the melted sand had all the desirable properties of the solid quartz disk so far as low expansion with change of temperature was concerned. In heating a bar of such material a meter in length from room temperature to 1000° C., the increase of length is only half a millimeter. Under ordinary temperature ranges encountered in an observatory dome, the quartz disk therefore retains its dimensions to so high a degree of precision that its optical surface is scarcely impaired at all. In order to provide a surface clear from bubbles or imperfections that might interfere with the grinding and polishing of the optical surface, he devised an oxy-hydrogen blowtorch that would spray pure melted quartz onto the top surface of the foundation disk.

While in itself pure quartz is a harder material than the usual borosilicate glass, the process of grinding and polishing such a disk into an optical mirror is actually expedited. The reason for this is that in the so-called "figuring" of the ordinary glass mirror, the slight movements of the polishing pad required to remove a trace of glass cause so material a rise in temperature as to distort appreciably the figure of the mirror, making it necessary to wait hours after each polishing process to allow the mirror to come again to uniform temperature for the purpose of the optical test required. In the case of quartz, on the other hand, the low cofficient of the expansion of the material renders it quite unnecessary to pause after each operation. During the "figuring" or perfecting of the final optical surface, operations on the surface and the necessary subsequent tests may follow each other in practical continuity. Through

months and years of painstaking work, Dr. Thomson and his co-workers succeeded in producing larger and larger quartz disks for astronomical purposes, several of which have already been useful for the purposes intended. With every increase in size, however, new difficulties arose which he surmounted until at length quartz disks of five feet in diameter were actually secured. Here progress towards success appeared to be approaching an asymptote. While no difficulties ahead seemed to him unconquerable, time and cost began to impose harsh limits so that, with many misgivings, it appeared expedient to revert to the more familiar and less expensive process of casting glass, if a sufficiently large disk for the 200-inch mirror were to be produced without undue delay.

It is now common knowledge that a large disk of Pyrex glass honeycombed to relieve excess weight was finally cast at the Corning Glass Works in March, 1934. Since Pyrex has a lower coefficient of expansion than the ordinary borosilicate glass, the finished product should show a considerable gain in performance in the direction to which Dr. Thomson devoted so much of his energy, even though the result must unfortunately fall short of the high ideal he had set. It is perhaps fair to remark that he was very reluctant to forego further work in the fusing of quartz for he was still confident that the troublesome obstacles which crept in with each increase in size were by no means insurmountable.

One cannot pass over the account of Dr. Thomson's contributions to the instrumental side of astronomy without a mention of the important part which he played in the making of the first large glass telescopic disk to be cast in the United States. This was the 70-inch disk of glass poured at the National Bureau of Standards in 1929 for the reflector of the newly-established Perkins Observatory. The Director of the Bureau of Standards at that time was Dr. S. W. Stratton, a life-long friend of Elihu Thomson. During the discouraging days Thomson offered the Bureau on many occasions important advice in regard to improvements in technique which finally resulted in the 70-inch borosilicate disk, thus making possible the first large telecope to be built entirely of materials fabricated in this country.

Dr. Thomson's interest in astronomy covered a wide variety of topics. While he was intrigued by the space-penetrating power of the projected 200-inch telescope, he was equally interested in the possibility that it might bring to light new information concerning the nearer bodies.

When in 1921 Professor William H. Pickering was contending for vegetation on the lunar surface as an explanation of the apparent changes in illumination observed in telescopes, Thomson's imagination met the challenge with a physical theory. From his early experiments with his friend, E. J. Houston, he had observed the changes of color of many substances when subjected to wide ranges of temperature. Oxides, sulphides, and salts of various metals, he noted, reddened when heated.

On the basis of these experiments, he therefore explained the observed changes in color of certain regions on the lunar surface where similar substances at low temperatures during the long lunar night would be raised to exceedingly high temperatures under the vertical solar rays of the long lunar day. Certain regions on the moon, therefore would have a tendency to darken on heating and to lighten again in the low temperatures accompanying the withdrawal of sunlight. This explanation, he felt, was a relief from the necessity of considering the existence of vegetation on a body devoid of water and any appreciable atmosphere.

The quickness of his mind in thus transferring observations from the laboratory to a new lunar theory is representative of one who examines relationships between phenomena in one field and those in another—a quality characteristic of genius marked with imagination.

It is not surprising that training as an electrical engineer constantly emphasized in his mind the probability that electrical forces would sooner or later come in for the solution of certain astronomical problems. The reappearance of Halley's Comet in 1910, heralded by the noted naked-eye comet, 1910 *a*, stimulated a paper entitled, "Some Considerations of the Nature of Comets and Their Possible Relation to the Sun." Supplementing the accepted views in regard to the volatilization of the materials in the comet's nucleus and the action of light pressure in the formation of the tail, he considered the possible electrical reactions between the sun and the comet itself.

He believed that ultraviolet radiation from the sun added its effect in causing a discharge of negative ions from the nucleus. Pointing out the extremely small amount of material in space that would suffice to form even a very large tail, he supposes the possibility that a comet in moving around the sun entangles itself in streams of material driven from the sun and that its behavior varies accordingly. "It is conceivable," he states, "that a comet may act as an indicator of the condition of space around the sun, the space in which the comet, for the time being, is moving. Even under the idea that there is volatile matter emitted from the sun which ordinarily would not be visible, let such matter strike into the nucleus of a comet and meet matter from the comet itself; it is easily seen that the interactions, electrical or otherwise, or even physical collisions, may add to the light of a comet's tail."

As comets and meteors appear intimately associated cosmically, so Thomson's interest and speculations likewise touched the realm of meteors. Two early astronomical events to which he attributes his early interest in astronomy occurred during his boyhood—the appearance of the Great Comet of 1858, and the spectacular shower of Leonids which occurred in 1866 and 1867. While the 1866 display was reported to be conspicuously fine in England, he states that he saw nothing of it in the United States, although he had especially watched for it. He describes in his papers, however, the brilliant shower that he observed on November 15, 1867, one of the thrills of his boyhood days.

A visit to Coon Butte in Arizona in the spring of 1911 was provocative of an extensive paper presented to the American Academy of Arts and Sciences, setting forth his views on the famous Meteor Crater.

Time does not permit an extended presentation of his many reflections upon the physics of meteor falls. Two deductions, however, may be made from his publications on this subject. One is that Dr. Thomson fully appreciated the part played by the compression of the air in advance of the meteor. It is a bit surprising, however, that he makes no mention of the possibility that the high rise in temperature in the atmospheric gases in advance of the meteor should result in an ionization of oxygen and hydrogen during the meteor's flight—an important factor in the present-day explanation of meteor trails. If it occurred to him, there seems to be no reference to this thought in the literature on the subject which he has written.

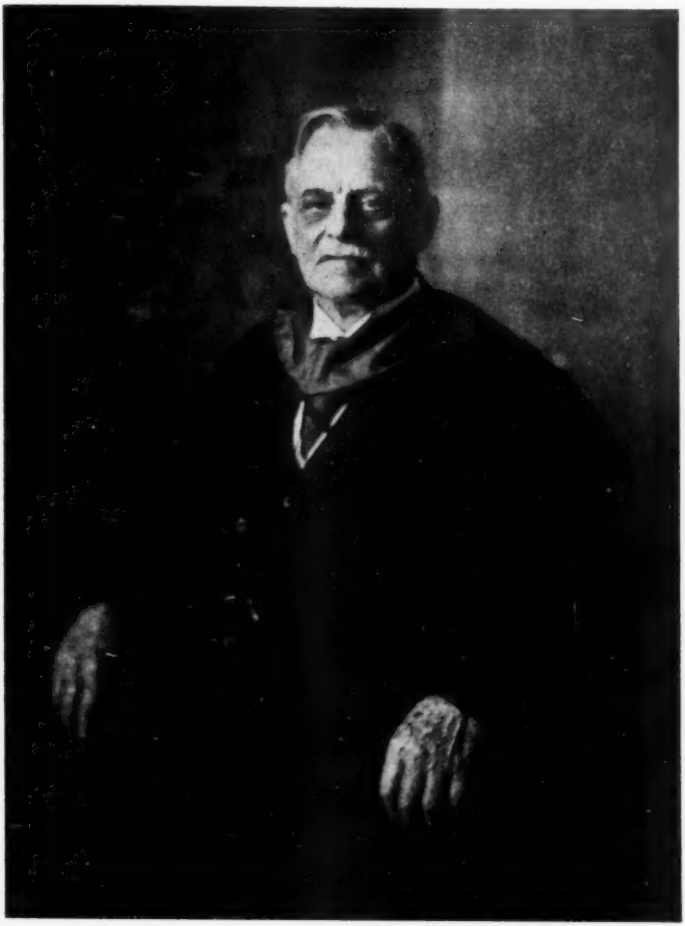
As a second deduction from his paper on Meteor Crater, we infer that he was not impressed with the views of those who believed that a large mass disintegrated before contact with the earth. Whether or not the results of more recent calculations, indicating that no single large mass could have survived the encounter with the earth's atmosphere were known to Dr. Thomson before his death, or whether or not that would have modified his views, I do not know.

With Professor Thomson's fundamental training and interests in electrical engineering, there is little wonder that we find him frequently speculating on the possible part which electricity plays in the astronomical realm. In 1894 when selecting a topic for the address before the Electrical Section of the Franklin Institute he chose for his subject, "Cosmic Electricity" and on the occasion of the opening of the Palmer Physical Laboratory in Princeton in 1909 he spoke on "Atmospheric Electricity." In 1916 he presented before the National Academy of Sciences a paper entitled "Inferences Concerning Auroras."

In a day when knowledge of ionization phenomena was even far more meager than it is today, it is interesting to note to what extent the imagination of this engineer was carried into the cosmic realm. When Professor Thomson was speculating he was quite aware both of the dangers and the importance of this sort of indulgence. "Where we have no definite knowledge," he says, "we are forced to speculation and often scientific speculation points a way to further advances in our theories." Differentiating even more closely between science and speculation, he made the apt remark, "While speculation is not science, science is often benefitted by speculative ideas. Speculation is the result of imagination —science of investigation."

He recognized, therefore, the complete lack of knowledge of actual facts supporting any theory of cosmic electricity, but nevertheless believed that since there is a well-known rise of positive potential with respect to the earth as one proceeds upwards into the atmosphere, there is a sufficient basis for speculation. The electrical potential at the top of

the Washington Monument may be three or four thousand volts above that of the ground. Assuming the increase to be equal to 1000 volts for each 100 feet of altitude, at a height of 20 miles, there would be a million volts difference in potential between such a region and the



ELIHU THOMSON

ground. From this he infers that there exists aloft a conducting layer of rarefied air which may possess a very considerable positive potential with respect to the earth. Thus in a vague way, Professor Thomson appears to have anticipated the hypothesis of an electrified region sur-

rounding the earth, a conception bordering on that now so generally recognized as the Kennelly-Heaviside layer. There appears, however, to be no reference in his speculations to any concept of electric waves travelling in such a region.

Lacking at that time any clear evidence for the existence of electrified gas molecules, he appears to rely upon water vapor droplets or dust particles for supporting charges in the upper atmosphere. In his picture the earth possesses the character of a huge conductor, the outer coating being rarefied conducting air, the inner coating the ground, the dielectric the dense air between. On this assumption, he regarded that a thunder storm might be brought about by a flaw in the dielectric due to the presence of clouds of vapor extending to great altitudes.

One difficulty with the theory is how the positive potential of the higher atmosphere can be maintained. If there were not some maintaining agent at work, equalization of the charges between the air and the earth would appear to be inevitable. This is where Professor Thomson supposes that influences outside the earth itself may be responsible for the electrification of the upper air.

He assumes a vast nebulous mass as having been the origin of the solar system and that such a nebulous mass may have had a small charge with respect to other gaseous masses in space. With the diminution of the surface during shrinkage, the potential of the charge increased, assuming the surrounding space to be a perfect non-conductor. This charge he supposes increased in potential until the smaller exterior particles were repelled outwards, thus balancing the centripetal tendency of gravity. With the dispersion of such particles there would result a fall in potential. Further concentration would raise the potential and we should therefore have alternate periods of dispersion and accumulation of charges while the mass of gas was evolving into the solar system. In this evolutionary picture based upon some form of a nebula hypothesis, he fancied electrified particles to be repelled periodically from the sun, ultimately reaching the earth's atmosphere.

A common exhibition of the streaming of such electrified particles he believes is contained in the coronal streamers seen during total eclipses of the sun. When such streams of electrified particles reach the upper atmosphere of the earth, thus disturbing the distribution of the charge within it, aurorae appear with the concomitant magnetic disturbances due to the induced effects. He goes so far as to assume that not only is the sun a charged body but probably the planets are also, and states, "It would be understood that some influence on the earth's condenser charge would exist, varying according to the positions relatively occupied by these bodies and particularly by the earth and the sun. This in turn would give rise to magnetic variations such as the diurnal, annual, and secular variations. It would account for the fact that the variations are greater when the earth is nearer the sun than when more remote." He suggests that the somewhat irregular sunspot period may be due to the

periodic accumulation of charge to a critical potential followed by a period of discharge when outer particles are repelled into space.

In his many years of observations of the polar lights, he was impressed with the fact that the curious converging of streamers to the zenith is but a matter of perspective. A paper presented to the National Academy of Sciences published in 1917 expresses his belief that all auroral streamers extend radially from the earth; the various archings and distortions exhibited to the eye being merely a matter of perspective due to the fact that an observer in a given locality objectively projects the luminous streamers orthogonally against the sky.

Of course much has developed since Professor Thomson's presentation of the subject to modify somewhat the simplicity of his explanation. That so many of his speculations have proved to be fundamentally sound is perhaps more surprising than that there should be considerable modifications in the details of his hypotheses; for he ventured them at a time when information on cosmic phenomena was far more scanty than it is today.

The solar corona, sunspot emanations, and auroral streamers were to him associated electrical phenomena. At times of maximum solar activity the solar corona is roughly circular in shape; at times of sunspot minima the extent of the corona in the equatorial region is far greater than at sunspot maxima and may be frequently far from symmetrical in shape. Statistical data show that in general aurorae are more conspicuous and more numerous at times of sunspot maxima than at times of sunspot minima, the maximum in auroral frequency falling perhaps one year after the maximum in solar activity as measured by sunspot numbers. Professor Thomson's contention that the sun, earth, and probably the other planets have electric charges holds wide implications. Perhaps we are now approacing an era when some kind of celestial electronics will form as important a branch of subject matter in astronomy as did the gravitational theory in the days subsequent to Newton.

It is obvious that Professor Thomson's interest in cosmic electricity which he so thoroughly believed played a part in the manifestations of the solar corona should entice him from his laboratory to observe eclipses of the sun whenever occasion made that possible.

The first total eclipse of the sun which Professor Thomson observed was that of the eclipse of 1900. On this occasion he was located at Barnsville, Georgia, and confesses that he was profoundly moved by this strange spectacle of nature. The eclipse of 1905 he observed from Spain. This appears to have been the occasion of an unusually bright corona for he states that "the huge corona prevented the darkness during totality being nearly so great as was the case in 1900."

Of course Professor Thomson had some advantages in observing eclipses not possible for the usual professional astronomer engaged in eclipse work. Preferring not to be hampered by the manipulation of technical instruments himself, he could gaze with the freedom of a lay-

man upon this outstanding spectacle of nature. Furthermore, even at the last moment he was free to change his location if threatening clouds jeopardized a clear view of the sun during the moments of totality. It was, I believe, at the 1918 eclipse in Colorado that Professor Thomson first made use of an automobile to avoid a cloud shadow that would have spelled complete failure for his observations.

At the occasion of the eclipse of January 24, 1925, he was with a group of over thirty friends in New Haven. During the extreme cold of that early January morning, he hired a taxi and drove out of New Haven to an open space to dodge a small cloud that seemed to him menacing. The eclipse, however, was one which occurred under very favorable circumstances with generally clear weather along its path east of Buffalo.

Two years later came the eclipse of the sun whose track crossed the Scandinavian Peninsula. By good fortune Professor Thomson was with the group of the McCormick-Chaloner expedition of the Smithsonian Institution, of which group I was a member. We located at Fagenes, Norway. It was disappointing to us all that an overcast sky following days of rain prevented any observations of the sun whatever during the eclipse. He took the disappointment with the highest type of sportsmanship. The journeyings of the next few days to Bergen and elsewhere presented, however, the opportunity for a growing friendship and a better understanding of the man whose imagination and interest made so many contributions to astronomy, even though it was but a side-line to his profession.

For the eclipse of 1932 Professor Thomson went to New Hampshire where the moon's shadow passed over the White Mountains. Those who recall this eclipse know the variety of the meteorological conditions that were encountered along its path. Professor Thomson repeated his escapades of 1918. Concerning his chase for a clear opening in the sky, Mrs. Thomson has written me as follows:

"In 1932 we went to the Mount Washington Hotel at Bretton Woods for our headquarters; and again met about thirty-five friends who had literally followed my husband there. Everyone would ask him where *he* was going to view an eclipse, and then go to the same place. The morning of the eclipse was overcast at Bretton Woods, and those who just sat on the hotel porch were doomed to disappointment, as it stayed cloudy there all day. We drove west, hoping for some opening in the sky, and got as far as Vermont. We then turned about, dashing in and out of the car, as the shadow was coming over the sun. We caught totality along the roadside—away from the madding crowd—somewhere outside of Bethlehem, as I remember it."

As an itinerant observer of solar eclipses, holding a car in readiness for meandering in any direction to avoid whatever cloud shadows interfered, Professor Thomson pioneered a new method in eclipse hunting. He often stressed that small portable apparatus, carried in a truck capable of movement up to the last few moments before totality, could out-

wit adverse meteorological conditions at a more permanent station. Through this ingenious use of the automobile, he was successful in seeing four out of a total of six eclipses which he attended—a rather better record than can be anticipated by the astronomer confined to a predetermined station by massive instruments requiring stable foundations which have to be erected in advance of the event.

It would be difficult to trace all the contributions to the science of astronomy that resulted from suggestions he so freely imparted. Doubtless a great many passed unrecorded. He was an inspiration to every worker in this science with whom he came in contact. Probably his most outstanding contributions to astronomy were on the instrumental side where his engineering skill and his painstaking work in perfecting the art of fusing quartz for optical surfaces may be regarded as an epochal advance in instrumental astronomy. The impact of his imagination has been felt in the various fields comprising the sun, moon, planets, terrestrial phenomena, and cosmic electricity. It is surprising to what degree subsequent years have justified much of his speculation. A lesser man would have lacked his boldness in advancing many hypotheses upon slender foundations. He published freely that others might prove or deny. We are well aware that in his interest in astronomy as in other fields he was in many respects in advance of his time.

Massachusetts Institute of Technology,
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The Annular Eclipse of April 7, 1940, at Chihuahua

By JOAQUIN GALLO

The National Astronomical Observatory sent an expedition to Chihuahua City, Capital of the Northern State of Chihuahua, to observe the Annular Eclipse of the Sun on April 7 of this year.

One of the purposes was to secure some pictures of the eclipse, with a photoheliograph by Dallmeyer, giving solar images of 10 cm. in diameter. Some of the pictures were made during the partial eclipse, while 6 were secured between the second and third contacts.

These plates were measured to determine the difference of coördinates between the moon and the sun, for comparison with that computed from the *American Ephemeris*.

As is known, the problem requires correcting the equatorial positions for parallax and refraction, if necessary, and computing the distances of the centers of the moon and sun at the moment of each plate. If the orientation is also known, the differences in α and δ can be obtained.

The motion of the upper atmosphere prevented the limbs from being well defined, so an error of 1″ is very probable.

The contacts also were observed with the photoheliograph and the differences, observed *minus* computed, are as follows:

1st	contact	$+10^s.0$
2nd	"	$+ 1.5$
3rd	"	$- 2.0$
4th	"	$- 1.0$

From the six plates between second and third contacts, we deduced a correction for the moon coördinates, $\Delta\alpha = -0^s.2$, $\Delta\delta = -1''$.

The error in α could be attributed also to longitude, but in this case the error should be 6^s, which is inadmissible.

The partial results of the plates are:

		O − C	
		$\Delta\alpha$	$\Delta\delta$
No.	5	$-2''.4$	$+0''.2$
	6	-5.2	$+0.5$
	7	-4.4	-0.2
	8	-2.9	-0.1
	9	-3.3	-2.7
	10	-1.8	-3.6

Besides, we made use of a refractor of 15 cm. by Grubb at night to show stars, clusters, and nebulae to the public and to boys from schools, contributing in this way to the popular culture. The day of the eclipse, the telescope was removed and instead a moving picture camera was used to obtain a film of the whole eclipse.

The instruments were installed in the court of the School No. 135, two miles south of the Cathedral. According to the position we were south of the line of centrality a very few seconds.

TACUBAYA, AUGUST 22, 1940

The Conjunction of Jupiter and Saturn of the Year 1563

By J. STEIN, S. J.

[*It will be noticed that there is not complete agreement between the dates of earlier triple conjunctions cited in this paper and those given by Professor Willard H. Garrett in the preceding issue. Some one with the necessary time and inclination may wish to attempt to reconcile the dates given or to establish entirely different ones.* ED.]

The highly interesting phenomenon of the triple conjunction of Jupiter and Saturn of this year has called the attention to other remarkable conjunctions of the two giant planets in the past. The conjunctions, as is well known, occur about every 20 years, but triple ones are very rare. The last of these was observed in the year 1682-3, the last but one in the year 1425.

Riccioli in his *Almagestum Novum I*, p. 676, makes mention of another triple conjunction, which should have occurred in the year 1563-4. According to the tabulae Alfonsinae the first one took place on 27 September 1563 in Leo, according to the tabulae Prutenicae on 26 August in Cancer; the second one on 26 January 1564 and the third one on 14 April in Cancer.

Calculating, by means of Neugebauer's chronological tables, the epoch of the conjunction, we find that the heliocentric conjunction of the two planets happened on 1 November 1563, the longitude L of the sun then being $= 117°$ and the heliocentric longitude of the earth, $E = 49°$. As, however, according to the well-known criterion, a triple conjunction is only possible when $L - E < 30°$, such a conjunction did *not* happen in the year 1563.

But in another respect this geocentric conjunction was most remarkable. Riccioli informs us that the conjunction was observed by Franciscus Junctinus[1] in Orange, on August 24, "hora 14.30′ post meridian," while Jupiter, more to the north, was occulting Saturn almost entirely (cum Jupiter borealior totum pene Saturnum tegerat). Calculating the astronomical longitudes λ and latitudes β on 23 and 24 August 1563, we find (the hours reckoned from Greenwich mean noon):

	λ Jup	λ Sat	β Jup	β Sat
Aug. 23 14^h	118°.85	118°.87	+0°.31	+0°.20
24 0	118.93	118.92	0.31	0.21
24 14	119.03	118.98	0.31	0.20

According to this the conjunction in geocentric longitude took place on August 23 at 21^h P.M., *i.e.*, on August 24 at 9^h A.M. But it must be taken into account that Neugebauer's tables give only two decimal places; consequently the result of our calculation may be 0°.01 or 0°.02 wrong, to which corresponds an uncertainty of 5 or 10 hours in the epoch.

Thus at the moment of the geocentric conjunction the difference in latitude and the apparent distance of the two planets was only one-tenth of a degree, and on account of the brightness of both, especially of Jupiter, it may have been hardly possible to see them separated with the naked eye.

CASTEL GANDOLFO, ITALY, 20 SEPTEMBER 1940.

[1] Franciscus Junctinus, S. Theol. Doctor, of Florence, born 7 March 1523, published in 1574 his "Speculum Astronomicum," full of astronomical tables and much erudition, and a "Sphaera" (Riccioli, *Alm. N. I*, pg. XXXIV).

An Improved Sotellunium*

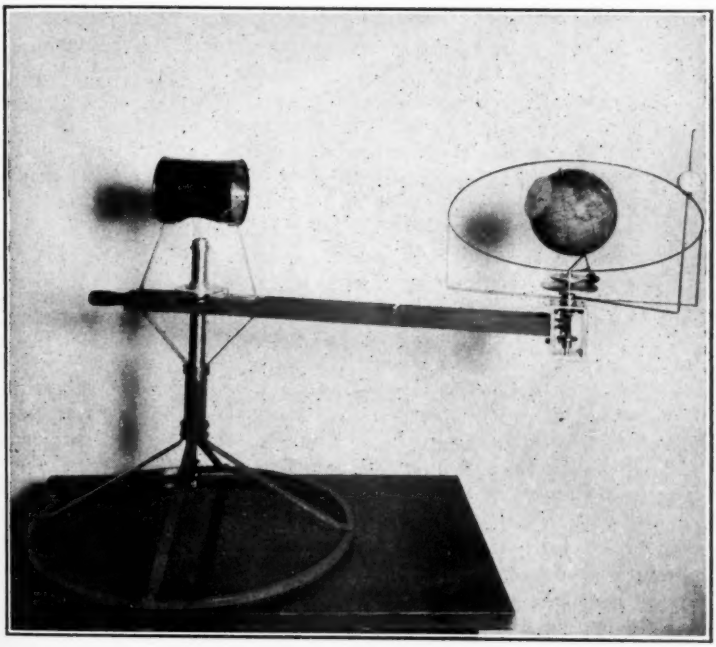
By W. G. COLGROVE, M.A.

In designing this mechanical instrument we were fully aware of the many attempts that had been made in this field to demonstrate the rather complex and difficult problems which are presented by the interrelations of the three bodies involved. Our experience in developing several other original aids to astronomical study made us rather careful about such matters as proportions and gear ratios, and our knowledge of some of the failures of other inventors made it necessary for us to refuse to follow in the beaten track. Many of their creations are unnecessarily involved and even fantastic, to say nothing of their frail construction, which renders them incapable of standing the rather vigorous handling of regular classroom demonstrations. It has been quite common practice to provide a hollow metal sphere for the sun instead of an electric light, so that even the seasons are not adequately shown, and seldom has anyone included the simple mechanism that produces the regression of the moon's nodes, which is so necessary to adequately demonstrate the recurrence of the phases of the moon and the repetition of the lunar and solar eclipses in the Metonic and Saros cycles.

In this instrument we present a unique combination of simplicity and ruggedness, together with compactness of design and comparative accuracy, only one approximate proportion being included, that of the diameters of the earth and the moon. We have learned that proportion is not essential and its absence is no handicap to the demonstrating value of the instrument. The problem of distances was solved by the limitations of portability and the space in one's car when conducting extension lectures with the instrument. The matter of diameters of the three bodies was determined by size of the electric lamp and the requirements of classroom work. The complete model is 4 feet long, 2 feet wide and 2½ feet high and can easily be carried on the rear seat of a car. It weighs only a few pounds. The earth is an ordinary globe, 6 inches in diameter, on which the usual features are easily visible and on whose surface solar eclipses are clearly shown. The size of the moon is made proportional to that of the earth for obvious reasons, and the sun-lamp is housed in a cylindrical reflector. The moon, of course, is much too near the earth, but its distance was determnied by our desire to show both the umbra and penumbra of the moon's shadow on the earth during solar eclipses and to keep the moon's orbit within the 2-foot limit of the base. These requirements made it necessary to greatly increase the inclination of the moon's orbit so that the moon's shadow would miss the

*A new model of the Sun-Earth-Moon System recently designed by the writer and built at the University of Western Ontario for its Department of Mathematics and Astronomy.

earth and the earth's shadow would miss the moon some of the time. This proved to be valuable, for, on account of the rather large diameter of the earth, we can provide a half dozen consecutive solar or lunar eclipses, so that the student can easily grasp these important phenomena without our revolving the earth many times to demonstrate widely separated eclipses. If we insisted on a model earth commensurate with the nine-inch radius of the moon's orbit, it would be necessary to reduce the earth's diameter to 1/4 and the moon's to 1/16 inch, but these could not be observed by a class, to say nothing of the larger audiences that attend extension lecture-demonstrations. This lack of proportion may seem a handicap, but the operation of the instrument will immediately prove its very real value.



THE SUN-EARTH-MOON MODEL.

The design of the mechanism with its gear ratios has required considerable time and ingenuity and its present compact appearance will doubtless commend itself to all who understand and appreciate mechanical assembly. The main column or central vertical axis is a rigid, tubular structure attached to a sturdy fabricated iron base with rubber protectors beneath; at its top is a strong electric lamp, to act as the sun, whose light is constantly directed toward the earth by a reflecting hood

which rotates around the stationary sun while the earth makes its annual revolution. This fixed sun-lamp has a wire equator attached so that the aim of the sun-spots, when present, may be indicated and understood through the recurring seasons of their period, and it will be quite apparent that during the spring the equator arches upward and in the fall it curves downward so that the effect of the sun-spots is almost nil, but during the summer and the winter seasons many of the spots aim directly at the earth and by their combined ultraviolet radiation and magnetic energy cause a variety of unusual disturbances in the earth's atmosphere and in our instruments of communication. The sun's rotation, however, soon carries the spots away from their earth-aim and their influence is directed into space. Just beneath the sun-lamp there is a graduated setting circle marked with degrees and minutes, as well as the months by which to show the heliocentric positions of the moon and planets and the monthly positions of the earth as it revolves around the sun. To this stationary vertical axis we have also attached the main driving gear meshed with a smaller gear fixed to the communicating shaft, which is carried in the hollow horizontal arm to convey the power to the unique train of gears in the open aluminum box beneath the earth. In this box are four spur gears which engage a variety of bevel gears to provide the various motions required. The result is eight-fold—a slight movement of the operating handle produces the revolution and the rotation of the earth, the revolution and rotation of the moon, the rotation of the earth's axis and the reverse rotation of the moon's orbit, the gradual ascent and descent of the moon on its arm to follow its orbit, and the apparent rise and fall of the equator of the sun as observed from the earth during each revolution. The earth's rotation is reduced to only 26 times, the moon's revolution to 6 times, and the moon's orbit to 13/12 times, for each revolution of the earth. This is done so that a class or audience may easily see what transpires. Just above this gear box will be found another graduated setting circle marked with hours and minutes, as well as the signs of the zodiac, by which to find the positions of the sun and the planets in right ascension and the constellations which form their background. This model demonstrates a great variety of astronomical phenomena connected with the Sun-Earth-Moon system. A slow counter-clockwise movement of the handle, with many stops in the course of a revolution of the earth, will cause the following demonstration to be easily made and numerous explanations to be readily understood:

The three important planes—Horizon, Equator, and Ecliptic, and their relations and functions.

The two graduated setting circles—the one beneath the sun for showing heliocentric positions such as the earth's longitude, the longitude of the earth's perihelion, the position of the line of apsides, and the earth's and sun's positions at any time. The other, below the earth, is for showing the R.A. of the planets as given in *The Observer's Handbook*, and the constellations of the zodiac where they are to be found at any time.

The period and velocity of rotation of all three bodies, day and night; the length of shadows, the apparent rising, culmination, and setting of the sun, moon, planets, and stars.

The inclination of the equators to the ecliptic, with the consequent direction of the axes, the advance of the seasons, the harvest moon, the midday night, the midnight day, the zones and the effect of solar radiation.

The sun's equator and the aim of the sun-spots, when present, on its surface. Their effect on atmosphere and communication.

The eccentricity of the orbits and its effect on distance, sun's radiation, tides, and eclipses.

The inclination of the orbits to the ecliptic.

The sidereal period of revolution of earth and monn and the synodic period of the moon.

The lunar apogee and perigee, the nodes and their regression, the moon's phases and librations in longitude.

The elongation, conjunction, quadrature, and opposition of the moon, as well as the positions where perturbations take place.

Eclipses of the sun and the moon—both partial and total.

Why the people in the southern hemisphere see the sun and the moon in the northern sky.

Why their seasons are the reverse of ours.

Why we have more and longer days in summer than in winter.

Why the sun is high in summer and low in winter.

The reason for and period of twilight.

Why the sun goes north at night.

Note: the audience is out in space and should imagine itself, for the observations, to be at the center of the horizon plane where the pin marks our latitude.

2 Christie Street, London, Ontario, Canada.

Planet Notes for December, 1940

By R. S. ZUG

Note: Greenwich Civil Time is employed unless otherwise stated. To obtain Eastern Standard Time subtract 5 hours, Central Standard Time, 6 hours, etc. The planetary phenomena are described as they are to be seen from latitude 45° N. The data are taken chiefly from the *American Ephemeris and Nautical Almanac*.

Sun. Apparent positions of the sun for December 1 and December 31, respectively, are: $\alpha = 16^h\,27^m.7$, $\delta = -21°\,45'.0$; $\alpha = 18^h\,39^m.9$, $\delta = -23°\,7'.6$. The sun will be found in the constellation Ophiuchus until December 18 when it enters the constellation Sagittarius. It will be moving through the latter constellation for the duration of December. The sun reaches the winter solstice on December 21, $23^h\,55^m$, which is the time of the beginning of the winter season.

Moon. Phenomena of the moon will occur as follows:

		h	m
First Quarter	Dec. 6	16	1
Full Moon	14	19	38
Last Quarter	22	1	45
New Moon	28	20	56
Apogee	Dec. 9	8	
Perigee	25	6	

Mercury. Mercury will be a morning star during December, but will remain quite inconspicuous due to its southerly declination and decreasing elongation from the sun.

Venus. Venus will remain a brilliant morning star of magnitude —3.5 during December. On December 1 the planet will rise about 3 hours before the sun, and by sunrise will have attained an altitude of some 25 degrees. By the end of the month the planet will precede the sun by only 2 hours in time of rising, due to decreasing elongation. The planet will be moving rapidly eastward through the constellation Libra until December 26 when it enters the constellation Sagittarius. On December 2, 12^h, Venus will be in conjunction with, and 1° 17′ to the north of, the planet Mars. On the morning of December 7 Venus will be situated about 2° south of the 3rd magnitude star α Librae.

Mars. Mars will be a morning star of magnitude +1.8 during December, and will be moving eastward through the constellation Libra, not far from the ecliptic. On the morning of December 12 the planet will be situated about 15′ north of the 3rd magnitude star α Librae. A conjunction with Venus will occur on December 2, as mentioned above.

Jupiter. Jupiter will be found during December as a bright star of magnitude —2.2, retrograding slowly through the constellation Aries. The retrograde motion ceases December 31. The planet is in a fine position for evening observation. An occultation of Jupiter will occur December 11, invisible from the United States.

Saturn. Saturn will be an evening star of magnitude about +0.2 and will be situated in the constellation Aries about 2° to the east of Jupiter. Like Jupiter, the planet Saturn will also be in slow retrograde motion during December, and will be well placed for evening observation. An occultation of Saturn will occur December 11, visible in the United States south of latitude 36° N. The limiting parallels of latitude between which the occultation will be visible are 36° N. to 28° S. The time of geocentric conjunction in right ascension of the moon and Saturn is December 11, $5^h\ 55^m.6$ Greenwich Civil Time.

Uranus. Uranus will be in slow retrograde motion near the eastern boundary of the constellation Taurus on December 1. By December 31 the planet in retrograding will have moved into the constellation Aries. Apparent positions of the planet for December 1 and December 31, respectively, are: $\alpha = 3^h\ 24^m.9$, $\delta = +18°\ 24'.0$; $\alpha = 3^h\ 20^m.8$, $\delta = +18°\ 9'.3$. The planet is in excellent position for evening observation.

Neptune. Neptune will be in western quadrature on December 19. Apparent positions of the planet for December 1 and December 31, respectively, are: $\alpha = 11^h\ 52^m.6$, $\delta = +2°\ 8'.5$; $\alpha = 11^h\ 53^m.6$, $\delta = +2°\ 4'.2$.

Asteroid Notes

By HUGH S. RICE

During the period November-December, Juno and Vesta are observable in the sky very late at night. Their apparent paths are roughly parallel to each other and not very far apart on the celestial sphere. Both planets will be more conveniently observed after the beginning of the year, but even in November and December Vesta, particularly, is in good position for telescope work.

The following directions will enable the observer to pick up these asteroids with a small instrument.

Juno is in Sextans during November and December. On the evening of November 8, it is 8°.5 due east of θ Hydrae. On November 30 it is 1° northeast of α (= 15) Sextantis. On December 16 Juno is 2° west of β Sextantis, and on January 1 it is about 1° west of the same star. The magnitude range is from 9.0 on November 8, to 8.6 on January 1. In early 1941 Juno will be brighter than usual for this planet.

Vesta is in and about the sickle of Leo during the period. On November 8, it is 7° northwest of Regulus and nearly 3° north on December 8. On January 1 it is 5° nearly northeast of the same star. The apparent movement in December being very slow, Vesta can be followed easily night after night. Its magnitude is 7.8 on November 8, 7.5 on December 1, and 7.0 on the last day of the year.

The next brightest minor planets for observation during this time are: 5 Astraea ($9^M.7$); 89 Julia ($9^M.7$); 16 Psyche ($9^M.1$); 51 Nemausa ($10^M.0$). We give ephemerides of these planets for a period around opposition time, the ephemerides having been computed by the Coppernicus-Institut.

EPHEMERIDES OF ASTEROIDS. FOR 0^h U.T. EQUINOX 1950.

5 ASTRAEA

		α h m	δ ° ′
Oct.	26	3 45.6	+11 8
Nov.	3	3 39.4	+10 32
	11	3 32.3	+ 9 58
	19	3 24.6	+ 9 28
	27	3 17.0	+ 9 4
Dec.	5	3 10.1	+ 8 49

16 PSYCHE

		α h m	δ ° ′
Nov.	11	4 53.0	+17 47
	19	4 46.9	+17 31
	27	4 39.8	+17 16
Dec.	5	4 32.4	+17 3
	13	4 25.4	+16 52
	21	4 19.2	+16 46

89 JULIA

		α h m	δ ° ′
Nov.	11	4 40.9	+47 15
	19	4 31.4	+47 4
	27	4 20.8	+46 31
Dec.	5	4 10.3	+45 36
	13	4 1.1	+44 23
	21	3 54.0	+42 57

51 NEMAUSA

		α h m	δ ° ′
Nov.	19	5 2.3	+ 7 11
	27	4 54.9	+ 6 32
Dec.	5	4 46.9	+ 6 2
	13	4 38.9	+ 5 44
	21	4 31.5	+ 5 39
	29	4 25.3	+ 5 47

Hayden Planetarium, American Museum of Natural History,
New York City, October 15, 1940.

Occultation Predictions

(Taken from the *American Ephemeris*)

The quantities in the columns *a* and *b* are given for the purpose of making these predictions useful for any place within 200 miles of the point indicated. The procedure is as follows: Subtract the longitude of the point given from

the longitude of the place in question; multiply the result in degrees, taking the signs into account, by the quantity under *a* for the star to be observed; similarly, with the latitude, using *b*; apply the sum of the products, with its proper sign, to the Greenwich C.T., and obtain the predicted Greenwich Civil Time for the phenomenon at the place of observation. To obtain Eastern Standard Time it is necessary to subtract five hours; Central Standard Time, six hours, etc.

Date 1940	Star	Mag.	IMMERSION Greenwich C.T.	*a*	*b*	Angle E from N	EMERSION Greenwich C.T.	*a*	*b*	Angle E from N
			h m	m	m	°	h m	m	m	°
Occultations Visible in Longitude +72° 30′, Latitude +42° 30′										
Dec. 1	BD—18°5155	6.3	22 19.4	—1.7	—2.7	131	22 59.5	+0.1	+1.1	204
6	293 B.Aqr	5.6	22 6.7	—1.9	+1.2	68	23 34.7	—1.7	+0.8	237
16	26 Gem	5.1	0 51.7	—0.3	+1.8	74	1 55.5	—0.9	+0.8	282
20	43 Leo	6.3	3 10.7	—0.2	—0.5	145	3 34.7	—0.2	+2.2	245
Occultations Visible in Longitude +91° 0′, Latitude +40° 0′										
Dec. 1	BD—18°5155	6.3	21 48.0	—2.1	—1.3	114	22 50.7	—0.9	+0.4	223
6	293 B.Aqr	5.6	21 32.6	—1.4	+2.1	54	22 56.6	—1.9	+1.1	255
16	26 Gem	5.1	0 48.0	+0.3	+1.8	64	1 41.1	—0.4	+0.6	291
19	o Leo	3.8	9 9.2	—2.5	+1.4	71	10 9.9	—1.1	—2.9	335
31	27 G.Cap	6.2	0 3.5	—0.8	—1.4	96	1 0.8	0.0	0.0	228
Occultations Visible in Longitude +120° 0′, Latitude +36° 0′										
Dec. 11	31 Ari	5.7	9 33.1	—1.1	+1.8	27	10 15.8	—0.2	—3.5	311
19	o Leo	3.8	8 13.9	—1.2	+0.7	103	9 29.2	—1.6	—0.1	292
20	35 Sex	6.3	14 24.2	—0.9	—2.8	156	15 22.7	—2.0	—0.5	256
25	o Lib	6.1	14 8.5	—1.0	—0.2	126	15 19.5	—1.8	+0.5	274

Comet Notes

By G. VAN BIESBROECK

During the last month three new comets have been announced.

Comet Cunningham was discovered by L. E. Cunningham on a photograph taken September 5 at the Oak Ridge station of the Harvard Observatory. It was afterwards also located on eleven plates taken there with small "patrol" cameras between August 25 and September 15. At discovery the comet was in the constellation of Cygnus and its brightness, estimated as $12^{M}.9$ on August 29, showed a rapid increase. From three approximate positions measured on the plates of August 25, September 5 and 9, the following preliminary elements have been computed:

Computer	L. E. Cunningham	A. D. Maxwell
Perihelion date	1941 Jan. 19.912	1941 Jan. 18.952
Perihelion to node	196° 6′	197° 29′
Longitude of node	299 50	299 2
Inclination	51 48	51 24
Perihelion distance	0.3813	0.3754

While more accurate elements will differ slightly from the above this information allows us to predict that the comet will come fairly close to the earth next January and will unquestionably reach naked-eye visibility. The character of the motion is well indicated by the following rough ephemeris supplied by Dr. Maxwell:

EPHEMERIS OF COMET CUNNINGHAM

1940	α h m	δ °	—Distance from— earth	sun	Mag.
Oct. 18	19 32	+46.5	1.56	1.95	+10.2
Nov. 7	16	39.4	1.41	1.63	8.8
27	17	32.2	1.23	1.28	7.0
Dec. 17	29	24.1	0.98	0.90	+ 4.2
1941					
Jan. 6	42	4.8	0.66	0.51	— 0.3
26	19 46	—41.7	0.80	0.42	— 1.2
Feb. 15	20 32	—46.4	1.29	0.79	+ 3.9
Mar. 7	21 08	—45.0	1.58	1.17	+ 6.9

It will be seen that during November and in the beginning of December the comet moves southward near the east boundary of Lyra. After that the motion increases south-eastward and by the middle of January the comet will be lost for northern observers. Naked-eye visibility is to be expected by the end of November and from all indications the comet may become a conspicuously bright object in January. A plate taken here on October 6 shows a sharp nucleus surrounded by a round head emitting a broad tail extending to 5′ in position angle 130°. The total brightness was estimated as 10^{M} on that day.

COMET WHIPPLE also was discovered at the Harvard Observatory. F. L. Whipple found that object on a plate of the Aquila region taken August 8. He afterwards recognized the image on a number of previous plates beginning July 29. His estimate of the magnitude was $10^{M}.5$ on August 5. But the discovery was not made until September 30 and by that time the comet had moved far into the southern hemisphere.

From the measures covering the interval July 29 to August 10 the following first elements have been computed:

	F. L. Whipple	A. D. Maxwell
Perihelion time	Oct. 7.894	Oct. 7.881
Perihelion to node	235° 16′	235° 15′.6
Longitude of node	134 10	134 9.8
Inclination	55 12	55 10.6
Perihelion distance	1.0875	1.08756

According to this orbit, maximum brightness came on the first of September. By the end of next January the comet will come again in reach of northern observers but its magnitude will then be reduced to 14.

The third new comet was announced from Tokyo (Japan) on October 5. The discoverer's name is given as Okabayasi and the following information was made available:

Magnitude 11. Nucleus.
1940 October 4 at $18^{h}\,49^{m}.0$ U.T.
Right ascension $10^{h}\,37^{m}\,31^{s}.1$. Declination +25° 13′ 1″.
Daily motion $1^{m}\,53^{s}$ east, 56′ north.

No further data have been published about this object.

Of the previously announced objects PERIODIC COMETS SCHWASSMANN-WACHMANN I and WHIPPLE are still observable in the evening sky. Both have been recorded here photographically but they are too faint for ordinary instruments.

If we count as the first comet of 1940 the somewhat dubious object Kulin, the

preliminary designation of this year's comets now stands as follows:

Discoverer	Designation
Kulin	1940 *a*
Periodic Whipple	1940 *b*
Periodic Schwassmann-Wachmann	1940 *c*
Cunningham	1940 *d*
Whipple	1940 *e*
Okabayasi	1940 *f*

Mt. Locke, Texas, October 11, 1940.

METEORS AND METEORITES

Meteor Notes from the American Meteor Society

By CHARLES P. OLIVIER, President

In the last Notes the preliminary results of the Perseid campaign were given for the stations relatively near Philadelphia. Since then, large numbers of reports have arrived, partly from our regular members but many from persons who undertook observations for the first time. In the accompanying table I have given the usual data. Press of work has prevented as yet the working up of the radiants certainly to be found on many of the maps. Incidentally a larger percent than usual of the meteors were plotted, though this type of work was naturally largely restricted to our regular observers. A most casual inspection of the table will show that this was a very ordinary return of the stream and not a rich one. Still persons working under favorable skies were well rewarded by the meteors they saw. In some places also considerable numbers of the Perseids were quite bright. Certain groups of observers deserve special mention.—The one known as the Youngstown, Ohio, group under W. H. Haas, reported for six nights in August. While Haas was the only one who plotted, the other observers, using our standard blanks, recorded full data for the meteors seen. There is good reason to think that this group, in connection with other Ohio observers, may become the center of an active network. They have certainly made an excellent start. Another group, as yet restricted to one family, is that under George E. Lambert of 3105 Decatur Avenue, Bronx, New York. Due to his excellent work, he will from now on be appointed as A.M.S. regional director for the Hudson River Valley and New York City, including such sections of northwest New England as can better coöperate with him than with the New Haven, Connecticut, group. I ask all observers in his territory, particularly those in New York City, to get into direct touch with him so that effective coöperative work may be planned and more regular observations made. G. E. Lambert himself and Miss Mildred Lambert have plotted the meteors personally observed; the other members of the family made valuable counts planned so that they would be of most use. The Des Moines, Iowa, group under H. M. Johnson, did good work on many nights. Observations from two stations, for parallax, on August 11 were stopped by clouds which rose shortly after work was started. This active group plans to continue observations for heights in future. We have not yet received a full report from the New Haven group. Only Mrs. G. C. Rademacher and her assistant, Miss Short, have sent in their results. It is understood that this group, as a whole, coöperated with Lambert in a program to determine heights. J. H. Pruett, our efficient West Coast regional director, sends in reports for some of his group. Others probably will follow from that region.

The group at Fremont, Ohio, under C. T. Hardy, again observed on many nights in July and August. In fact, Ohio showed up particularly well during the past summer. A glance at the table will make it very clear that several individual observers worked on many nights with energy and success. However, every one has done his part in extending our knowledge of this very interesting meteor stream, and what was accomplished in 1940 in America will help in the solution of the many problems which still remain, connected with the Perseids.

The moon will be full on October 16 and November 14, dates which interfere seriously with the Orionids and Leonids. In the former case, last quarter being on October 24, it should be possible to do good work from October 23 to 28, inclusive, with a diminishing handicap of moonlight. The Orionid meteors are too important to neglect any year, and though the maximum usually comes on October 19, yet in recent years equally good numbers are often seen for several days thereafter and indeed a moderately good rate up to October 28. Full moon will be just two days before the expected best date for the Leonids. As they are now so far past their 33-year maximum, their hourly numbers are probably low at best. But as many Leonids are bright and leave good trains, I hope that our members will observe at least on one night, preferably that of November 16/17, or, if that is cloudy, the next. The Giacobinids are due on October 9, if they come at all. I hope observers will be on the lookout that night, as well as the one before and after, in case they should pleasantly surprise us with a good—and unexpected—display.

Observer and Station	Date 1940	Began	Ended	Min.	F.	Met.	*
Haas, W. H., New Waterford, Ohio	Aug. 6	13:18	14:18	60	1.0	18	1
	7	14:54	15:54	60	1.0	11	2
	9	13:14	15:28	134	0.9	17	3
	10	12:00	16:02	200	0.9	108	4
Grandmontague, L. F., New Waterford	10	12:00	16:02	200	0.9	91	5
Beede, New Waterford, Ohio	10	12:00	16:02	200	0.9	38	6
Haas, W. H., New Waterford, Ohio	11	13:50	15:40	110	0.9	22	7
	12	14:15	15:15	60	1.0	48	8
Dole, R. M., Cape Elizabeth, Me.	10	14:10	15:10	60	0.4	27	9
	12	12:00	15:10	190	1.0	58	10
McAlen, J. J., N. Cambridge, Mass.	5	9:15	10:45	90	...	12	
	7	9:30	10:15	45	...	16	
	8	8:45	10:20	95	...	8	
	9	9:00	10:40	100	...	14	
	10	9:00	10:45	105	...	22	
	11	9:00	11:30	150	...	30	
	12	9:00	10:30	90	...	24	
Knafft, E., Ephrata, Pa.	4	8:00	9:00	60	...	45	
Datz, T., +3, Ebensburg, Pa.	11	12:15	13:15	60	0.4	44	11
Hardy, C. T., Fremont, Ohio	July 27	11:25	13:45	135	0.6	33	12
Zucker, D., Fremont, Ohio	27	11:38	13:38	120	0.6	13	13
Hardy, C. T., Fremont, Ohio	28	10:36	12:45	120	0.8	33	14
	Aug. 8	11:36	13:36	120	0.8	40	15
	10	11:17	14:17	180	0.4	57	14
Brown, R. P., Vancouver, Canada	July 4	11:35	13:35	120	0.7	11	16
	Aug. 3	10:10	14:10	240	1.0	66	16
	5	11:05	15:05	240	0.8	58	17
	7	9:31	13:53	252	0.8	43	16
Smith, F. W., Thiells, New York	9	9:00	10:00	60	1.0	6	18
	10	11:30	12:00	30	1.0	3	18
	11	12:30	13:30	60	1.0	7	19
Patch, R. J., Washington, D. C.	12	8:45	9:45	60	...	8	20
Scatchand, T. L., Glenside, Pa.	11	10:00	11:00	60	...	17	
	12	12:00	13:00	60	...	26	

Observer and Station	Date 1940	Began	Ended	Min.	F.	Met.	*
Naylor, C. D., Norristown, Pa.	10	12:00	13:00	60	...	11	
Preston, H., Birmingham, Mich.	8	10:50	12:10	80	0.9	9	
Borden, W. A., Birmingham, Mich.	July 31	10:10	12:30	140	0.9	24	21
	July 31	10:10	12:30	140	0.9	24	21
	Aug. 1	10:30	11:45	75	0.6	10	21
	4	10:15	13:45	210	0.9	36	21
	6	11:15	12:45	90	1.0	18	21
	7	11:00	12:30	90	0.9	22	21
	8	10:45	12:45	120	0.9	30	21
	10	10:25	12:30	125	1.0	29	21
	11	15:00	16:20	80	0.2	21	21
Lambert, G. E., Bronx, N. Y.	7	10:25	12:35	130	0.8	6	20
	10	12:17	14:46	149	0.9	15	20
Lambert, Margarite, Fishkill, N. Y.	10	11:17	13:46	149	0.9	50	
Lambert, Elie, Fishkill, N. Y.	10	11:17	13:46	149	0.9	49	
Lambert, Josephine, Fishkill, N. Y.	10	11:17	13:46	149	0.9	46	
Lambert, Gloria, Fishkill, N. Y.	10	11:17	13:46	149	0.9	39	
Lambert, G. E., Bronx, N. Y.	11	11:00	12:30	90	...	10	20
	20	10:52	12:45	113	0.7	5	
	23	10:50	12:50	120	1.0	7	
Lambert, Mildred, Bronx, N. Y.	20	10:52	12:45	113	0.7	6	
	23	10:50	12:50	120	1.0	8	
	Sept. 2	10:25	13:15	170	1.0	10	
Johnson, M. C., Des Moines, Ia.	Aug. 1	13:00	16:05	180	0.7	36	14
Vaughn, F., Des Moines, Ia.	3	13:45	14:45	60	0.7	25	15
Johnson, M. C., Des Moines, Ia.	3	14:00	16:00	120	0.7	25	14
	5	13:55	16:05	120	0.7	20	14
	6	13:00	16:00	180	1.0	37	14
Vaughn, F., Camp Dodge, Ia.	11	12:22	15:07	165	0.8	8	22
Beamer, C., Camp Dodge, Ia.	11	12:21	15:07	166	0.8	12	23
Chenell, A. E., Melcher, Ia.	11	11:55	13:15	80	0.8	3	24
Johnson, H. M., Melcher, Ia.	11	12:00	13:16	196	0.8	5	25
De Laney, M. C., Camp Dodge, Ia.	11	13:33	14:33	60	0.8	54	26
Tusant, J. B., Camp Dodge, Ia.	11	12:17	13:17	60	0.8	14	27
Johnson, M. C., Melcher, Ia.	11	12:00	13:15	75	0.8	23	
Johnson, M. C., Des Moines, Ia.	12	13:30	15:30	120	0.8	29	
Rademacher, Mrs. G. C.	July 28	8:30	12:00	210	1.0	46	20
Cutchogue, N. Y.	Aug. 10	11:	13:	120	0.8	63	20
	24	9:45	11:00	75	0.7	6	20
Short, B., Cutchogue, N. Y.	10	11:	13:	120	0.8	22	20
	24	9:45	11:00	75	0.7	3	20
Turner, T. W., +3, Quincy, Ill.	11	13:45	14:45	60	...	151	11
	11	14:45	15:45	60	...	117	11
Strom, Doris, +2, Dalton, Pa.	11	12:00	13:00	60	?	96	
McArthur, C., N. Quincy, Mass.	1	12:55	14:46	109	0.9	31	20
Lewis, C. M., +2, State College, Pa.	11	10:04	11:04	60	0.9	41	
Sundin, H., Jamestown, N. Y.	11	12:15	14:45	150	?	110	
Garrigan, L. N., Springdale, Pa.	11	10:00	13:00	180	?	36	
Blaisdell, Mrs. D., Weston, Ore.	11	12:05	12:25	20	1.0	17	
Cox, Mrs. L. B., Yucca, Ore.	11	11:10	12:40	90	...	73	
Thompson, Mrs. F., Eugene, Ore.	11	13:33	14:33	60	1.0	45	
	12	13:30	14:30	60	0.9	43	
	13	13:30	14:30	60	0.9	14	
Thompson, Betty, Eugene, Ore.	11	13:33	14:33	60	1.0	41	
	12	13:30	14:30	60	0.9	25	
	13	13:30	14:30	60	0.9	21	
Pruett, J. H., Eugene, Ore.	12	13:20	15:20	120	0.9	68	28
Parker, P. O., Ooltewah, Tenn.	10	11:40	14:30	170	0.7	27	29
Lambert, Mildred, Fishkill, N. Y.	3	11:49	14:25	156	1.0	55	20
Dole, R. M., Cape Elizabeth, Me.	1	10:00	11:00	60	1.0	10	20
	3	9:30	11:30	120	1.0	31	20

Observer and Station	Date 1940	Began	Ended	Min.	F.	Met.	*
Wallace, B., E. Cleveland, Ohio	July 31	12:00	16:00	240	1.0	39	30
	Aug. 1	11:50	14:30	160	1.0	30	30
	6	11:40	15:00	200	1.0	37	30
	7	11:30	13:15	105	...	14	30
	Sept. 3	12:10	15:40	210	1.0	18	30
	5	13:00	15:30	150	1.0	21	30
Dietrich, W., Triadelphia, W. Va.	Aug. 12	13:10	16:10	180	...	86	

Notes

1—6 Perseids; obs. to E.
2—3 Perseids; obs. to E.
3—7 Perseids; all plotted.
4—50+ Perseids; obs. to S.
5—59 Perseids; obs. to E.
6—11 Perseids; obs. to N.
7—17 Perseids; all plotted.
8—29 Perseids; obs. to E.
9—27 Perseids.
10—46 Perseids; all plotted.
11—No duplicates.
12—Obs. to NW.
13—Obs. to NE.
14—Obs. to E.
15—Obs. to N.
16—Data given.
17—Data given; 10 plotted.
18—3 Perseids.
19—6 Perseids.
20—All plotted.
21—Most plotted.
22—All plotted; 6 Perseids.
23—All plotted; 8 Perseids.
24—All plotted; obs. to NW.
25—All plotted; obs. to NW.
26—Obs. to W.
27—Obs. to S.
28—52 Perseids.
29—All plotted; 24 Perseids.
30—Part plotted.

1940 September 11, Flower Observatory, Upper Darby, Pennsylvania.

Contributions of the Society for Research on Meteorites

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New Data concerning the Fall of the Great [Tungus] Meteorite on June 30, 1908, in Central Siberia

By I. S. ASTAPOWITSCH

Translated by LINCOLN LA PAZ *and* GERHARD WIENS,
with Critical Commentaries by LINCOLN LA PAZ

[*Continued from the C.S.R.M. in the October issue.*]

§6. *Results of Measurements of the Barograms and Determination of the Moment of Explosion.*—In order to determine the precision of the measurements of the barograms and to ascertain, on the whole, the degree of reliability of the data received, we painstakingly measured, 5 times, the distances between the basic points 7^h to 13^h, 21^h[$? = 13^h$] to 21^h, [and between] 7^h to 7^h, 13^h to 13^h, and 21^h to 21^h (*i.e.*, the length for 24^h); by this means we could detect any lack of uniformity in the revolutions of the cylinder; none, however, was discovered. Excluding the stations that had unreliable records (Nos. 3, 5, 6, 12, 20, 21, 22), we learned from a comparison of the internal agreement of the recordings that the

average error in the marking of the datum (*i.e.*, the mark at 7^h, 13^h, and 21^h) by the observer was ± 0.17 mm., which corresponds to $\pm 6^m1$; by repeatedly measuring one and the same distance, we found that the average error of the measurement itself was ± 0.067 mm., which corresponds to $\pm 2^m4$; finally, the error of the scale may amount to $\pm 0^m3$ for 1^h of time. Thus, the accidental error in the moment to be measured, in the "time system" of the meteorological station, equals

$$\sqrt{(6.1)^2 + (2.4)^2 + (0.3)^2} = 6^m6;$$

unfortunately, the correction of the "time system" of the meteorological station in respect to local time is not known; its amount will be determined hereafter, from a comparison of all moments. The meteorite fell shortly after 7^h; hence, the influence of the third error indicated is not great; besides, they all become insignificant in comparison with the error of the zero of reckoning, as indicated, which amounts to one-half hour and more (Table 3).

TABLE 3

Determination of the moment of explosion according to the barograms.

No.	Place	λ (E.)	t	t, *Gr.*	r	Δt	T_o
		h m	h m	h m	km	m	h m
1	Tulun	6 41.5	8 08	1 26	660	34.5	0 52
2	Kirensk	7 12.5	7 48	0 36	450	23.6	0 12
3	Turukhansk	5 50.5	6 44	0 53	820	42.9	0 10
4	Khatanga	6 49.3	8 02	1 13	1100	58.1	0 15
5	Olkhon	7 07.6	8 17	1 09	860	45.0	0 24
6	Perevalnaya	7 30.5	8 18	0 47	1160	60.8	23 46
7	Irkutsk	6 57.2	7 29	0 32	910	47.6	23 44
8	(Troitskosavsk)	7 05.8	8 34	1 28	1130	59.2	0 29
9	Chita	7 34.0	8 22	0 48	1130	59.2	23 49
10	Tunka	6 50.2	7 58	1 08	990	51.8	0 16
11	Kultuk	6 54.8	8 12	1 17	970	50.8	0 26
12	Kabansk	7 06.6	8 22	1 16	990	51.6	0 24
13	Sretensk	7 50.8	7 31	23 40	1230	64.4	22 36
14	Peschanaya Bukhta	7 02.9	7 57	0 54	990	51.6	0 02
15	(Myssovskaya)	7 03.0	7 29	0 25	940	49.2	23 36

The position of the wave, recorded in the form of a line, was measured with great care on the barograms. Table 3 shows the longitude, λ, of the station in time, the moment, t, of the arrival of the wave, according to the barogram, the same in Greenwich time, t, *Gr.*, the distance, r, in km., from the place of the explosion (the center of the wind-fallen woods, according to our map, *ante*), the time, Δt, required by the air-wave to travel this distance, and the Greenwich time of the moment of the explosion, T_o.

The velocity of propagation of the air-waves was assumed to be 10°3 of the arc of the meridian per hour, or 19.09 km./min. (318.0 m./sec.), as obtained in connection with the explosion of the volcano Krakatoa in 1883.[V] [The names of the] stations with doubtful data are inclosed in parentheses. We supplement this table with the data obtained by V. Shostakovich (he, also, gives the T_o):

[16] Dagersky Mayak ($7^h 19^m5$; t,Gr.$=1^h 05^m$) : $r=$ 800 km; $t=41^m8$; $T_o=0^h 23^m$;
[17] Verkhoyansk ($8^h 54^m3$; t,Gr.$=1^h 19^m$) : $r=1680$ km; $t=87^m9$; $T_o=23^h 51^m$.

In examining the T_o, one is struck by the fact that, for all stations situated along the railroad, the moment recorded is 30^m behind the $T_o = 0^h 17^m$ deduced from seismic records.[15] If we assume that the meteorological stations used not the local, but [St.] Petersburg time (then effective on railroads), which was $2^h 01^m$

ahead of Greenwich time, which possibility A. Voznessensky does not exclude, then the difference can be explained; in that case, Sretensk was still another hour behind. Then we obtain the following table (Table 4).

TABLE 4

The moment of explosion, June 30, 1908, according to data of barograms.

No.	Place	T_0	No.	Place	T_0
		h m			h m
1	Tulun	0 33	10	Tunka	0 16
2	Kirensk	0 12	11	Kultuk	0 20
3	Turukhansk	0 10	12	Kabansk	0 24
4	Khatanga	0 15	13	Sretensk	0 25
5	Olkhon	0 24	14	Peschanaya Bukhta	0 02
6	Perevalnaya	0 16	15	(Myssovskaya)	23 40
7	Irkutsk	23 44	16	Dagersky Mayak	0 23
8	(Troitskosavsk)	0 29	17	(Verkhoyansk)	23 51
9	Chita	0 22			

Average: $0^h 13^m3$

If we exclude [the data for] Irkutsk and Verkhoyansk as deviating sharply from the other data, and [those for] Troitskosavsk and Myssovskaya as very doubtful, we obtain $T_0 = 0^h 16^m8 \pm 2^m2$; the average square error of one station is $\pm 7^m9$.

On the "Khatanga" barogram is clearly seen at first an increase of pressure of 0.7 mm.; then, after a few minutes, a decrease of 0.4 mm.; to check this [behavior], we measured on all barograms the position of the maximum (M) and of the minimum (m) of the amplitude in relation to the moment of passage through the mean value (m_0); regardless of individual deviations, it was found that, on the average, $M - m_0 = +0.052$ mm., $m_0 - m = +0.059$ mm.; *i.e., first,* the maximum of pressure in the deflection was, in absolute value, less than the minimum, and, *second,* it preceded the minimum by 4^m0; for comparison, let us note that the measurements of the Sprung microbarograms at Slutsk showed an initial increase of pressure of 0.10 mm. for 4^m and a series of more rapid oscillations, 5 or 6 in number, during the next 10^m to 12^m, with a diminishing amplitude. Whipple[50] gives the average of 6 microbarograms, which also show at first an increase of pressure of 0.030 mm. during 3^m to 4^m, then a decrease of 0.131 mm. during 3^m5, and 4 succeeding, extinguishing waves of a period of 2^m2, on which are then superimposed 3 groups of ballistic waves (see hereafter), which were not recorded by the Sprung microbarograph, because of a soiled pen.

In the seismogram (Fig. 3 [omitted here]) of the Irkutsk Observatory it may be seen that on the extinguishing seismic oscillation is superimposed, 3 times, a wave of a different kind, an air-wave, as has been determined (A. Voznessen-

TABLE 5

Determination of the moment of explosion according to sound phenomena (A. Voznessensky).

No.	Place	t	$t, Gr.$	T_0
		h m	h m	h m
1	Kansk	7 27	0 46	0 20
2	Troitskoye	7 05	45	18
3	Zamzor	7 32	43	16
4	Nizhne-Ilimsk	7 15	20	05
5	Nikolayevsky Factory	7 30	43	21

Mean $T_0 = 0^h 16^m0 \pm 2^m9$

sky[15]), which caused these distortions during its passage across the surface of the Earth; they are oscillations of a period of 2^m3. Thus vanishes every doubt that the oscillations of pressure described previously had a common cause.

From Table 4, it is seen that the moment of the explosion is fixed at June 30, $0^h\,16^m8 \pm 2^m2$. [In 1938, Astapowitsch gave $0^h\,16^m16 \pm 31^s$ as the mean of all determinations, *P. A.*, **46**, 314, 1938.] For comparison, we present Table 5, of A. Voznessensky,[21] in which he lists the moments of the arrival of the sound-waves at various points.

Table 6 gives the moments taken from other data.[72] Whipple believes that in observation (2), Table 6, there is an obvious error of 1^h in the change of time; in that case, we obtain, as an average, $T_0 = 0^h\,15^m4 \pm 3^m6$.

TABLE 6

Determination of the moment of explosion according to sound phenomena.

No.	Place	t	$t, Gr.$	T_0
		h m	h m	h m
1	Kuryshi-Popovich	—	0 37	0 12
2	Stepanovsky Pr.	—	(23) 43	(23) 16
3	Kezhma	7 07	0 23	0 12
4	Kezhma	7 22	0 38	0 27
5	Nizhne-Ilimsk	7 20	0 25	0 10

The arrival of the air-wave at Irkutsk was recorded by the Repsold and Milne seismograph; assuming for the velocity of its propagation the same rate (we know that the velocities of infra-sound-waves are practically the same: Esklangon [Esclangon]), we obtain T_0 independently (see Table 7).

TABLE 7

Determination of the moment of explosion according to air-waves recorded by the seismograph at Irkutsk.

No.	Pendulum	$t, Gr.$	Δt	T_0
		h m	m	h m
1	Repsold, east	1 03.1	47.6	0 15.5
2	Repsold, west	1 03.1	47.6	15.5
3	Milne	1 05.4	47.6	17.7

Mean $T_0 = 0^h\,16^m2 \pm 0^m7$

In Table 8 are given the data according to the barogram of the Sprung apparatus (at Slutsk). The main maximum, first in order of time, is indicated by M_1, the minimum following it, by m_1; the distance along the arc of the great circle is taken as 33°55.

TABLE 8

Determination of the moment of explosion according to the microbarogram at Slutsk.

No.	Wave	t	λ (E.)	$t, Gr.$	Δt	T_0
		h m	h m	h m	h m	h m
1	M_1	5 32	2 01.7	3 30.2	3 15.2	0 15.0
2	m_1	5 36	2 01.7	3 34.2	3 15.2	—

The agreement with the preceding results is fairly close, and we may conclude that the velocity of the air-waves from the explosion of Krakatoa in 1883, and those from the explosion at the fall of the meteorite of June 30, 1908, was the same. On this same barogram are registered several rapidly damped-out waves at $5^h\,37^m5$, $5^h\,39^m5$, and $5^h\,42^m5$; on the other barograph at Slutsk, which makes dot-

ted perforations every 10^m, the perforation at $5^h\,40^m$ shows a noticeable deflection (of the order of 0.2 to 0.3 mm.); on the same perforating kind of Hassler barograph, at the Leningrad station, no deflections can be seen—obviously the maximum occurred between the recordings. The Reinacher barograph at the Leningrad station, which has a 48-hour tape and a vertical scale on which 1 mm. = 1 mm. Hg, recorded a faint wave of an amplitude of approximately 0.2 mm. (Sprung at Slutsk, 0.22 mm.), with a maximum at $5^h\,34^m$ and a minimum at $5^h\,36^m$ in a very distinct recording line; Table 9 gives the T_0.

TABLE 9

Determination of the moment of explosion according to the barogram at the Leningrad station.

No.	Wave	t	λ (E.)	t, *Gr.*	Δt	T_0
		h m	h m	h m	h m	h m
1	M_1	5 34	2 01.2	3 32.8	3 15.2	0 17.6
2	m_1	5 36	2 01.2	3 34.8	3 15.2	—

On the weekly barogram of the typical Richard model at the Moscow Geophysical Institute, the author did not detect any noticeable recordings between 5^h and 6^h; 1 mm. of the vertical scale here corresponds to 0.5 mm. Hg.

In his work,[50] Whipple gives magnified copies of the micrograms from 6 English stations and gives the moments of the first (main) minimum, m_1, excluding one station, on account of the unreliability of its registration. We were interested in the moment, M_1, examined previously; so we measured its position on the microbarograms. Assuming more exact coördinates for the epicenter ($\phi = +60°\,54'$; $\lambda =$ E. $101°\,54'$) and granting the same velocity for the propagation of the waves as before, we obtained the following values of T_0 (Table 10).

TABLE 10

Determination of the moment of explosion according to barograms of English stations.

No.	Station	t, *Gr.*	r	Δt	T_0
		h m	km	h m	h m
1	Kensington	5 19	5743	5 01	0 18
2	Westminster	03	5743	5 01	02
3	Reading	16	5778	5 02	14
4	Cambridge	02	5670	4 57	05
5	Petersfield	19	5825	5 05	14

Mean $T_0 = 0^h\,10^m6 \pm 3^m0$

Thus, the correction of the time of the English stations also turned out to be considerable, and the average square error of one station is $\pm 6^m8$ (for the Russian stations, after the deduction of systematic errors, it is $\pm 7^m5$).

Besides determining the moment of the arrival of the air-waves ("manometric shock," according to Esklangon), we measured the amplitude on the same barograms (Table 2, *ante*). As a simple average of all measurements, it was found that the maximum lies 0.41 mm., and the minimum, 0.49 mm., from the central line of the record. The same *asymmetry* is evident on the microbarograms at Slutsk, London, Cambridge, Petersfield, and Reading.

The picture is very reminiscent of the curves registered by military sound-measuring instruments. To every type of cannon corresponds a certain type of curve; the greater the power and the caliber of the cannon, the greater are the amplitude of the waves and their number; this fact, however, applies to only the "muzzle" waves, which arise at the discharge, as distinguished from the Mach

waves, today termed "ballistic waves," which are produced by the flying shell. To the ear, these waves seem alike, whereas the sound-measuring instruments distinguish sharply between them: the ballistic wave, perceived by the ear as a sharp clap, is accompanied by scarcely any change in pressure, whereas the "muzzle" wave shows a basic amplitude. The "muzzle" wave is the so-called shock wave, which is produced in general at every powerful explosion and has not necessarily the frequency of sound, belonging largely to the region of infra-sound-vibrations. The latter are decidedly less subject to absorption and are still clearly revealed when the sound of the explosion is no longer heard.[VI] Esklangon found that, under the same conditions, the velocities of infra-sound-waves are equal to the usual velocities of sound-waves; near the place of explosion they may exceed even 1,000 m./sec., but, even for the large ordnance of the present day, their velocity becomes normal at a distance of 1 km. All these facts lead one to believe that: (1) the "manometric shock" on all the barograms [examined] belonged to an explosive wave of infrasonic frequency, accompanied during the first 30^m to 35^m by a series of sound-waves of low frequencies, which disappeared fairly soon; (2) the detonation of the ballistic wave of the meteorite (or meteorites), which spread through the free atmosphere, was noted also by observers, but perhaps only in England by instruments (at $5^h\,25^m$ G.M.T.); (3) apparently there was noted a whistle which, as is known from the acoustics of cannon shells, has no relation to the ballistic wave, but was produced by the vortices in the rarefied region behind the meteorite; (4) there was no dead zone of audibility or any anomalous zone; indeed, there could not have been any, in view of the magnitude of the explosion (Whipple admitted the possibility of its existence); (5) simultaneously with the flight there were heard mysterious sounds, apparently of electric origin (E. Sarychev[19]); these cannot be disregarded (Whipple), since they are attested for several dozen other bolides by thoroughly reliable observers[VII] and are kindred, possibly, to the sounds occasionally accompanying the aurora borealis. This phenomenon, it is true, has not been at all sufficiently studied, but it should not be denied.

Measurements of the amplitudes of the oscillations disclosed that they decreased approximately in inverse proportion to the distance; this fact supports Whipple's opinion that the wave traveled with a vertical front and expanded as a flat wave; the product of the distance from the explosion and the amplitude for 13 barograms gave: $r \times A = 1048 \pm 185$ mm./km. (rejecting as doubtful: Troitskosavsk, with an amplitude of 0.1 mm., and Perevalnaya, with an amplitude of 0.05 mm.). Sretensk and Mysovaya deviate sharply from the general course; if we exclude them, we obtain $r \times A = 1043 \pm 135$; for Slutsk, $r \times A = 820$ (for Leningrad, 745); and for England (mean), 777 mm./km.

§7. *Seismic Data.*—In 1930, A. Treskov (Irkutsk) informed the author that, besides the known Irkutsk record of the earthquake, studied in detail by A. Voznessensky, there was a record of it likewise at Tiflis and at Tashkent. This was discovered independently also by Whipple, who added to this [information] the data from Jena, according to the collated *Catalog of the Central Bureau of the International Seismic Association,* Strassburg, 1913. A. Treskov points out that in analyzing the seismograms of 1908, the moments of the beginning of vibrations, the moments of the beginning of distinct vibrations, and the moment of the greatest swing of the pendulum, N, were noted; assuming that the differences between the moments, M, corresponded to the differences between the arrivals (at the stations) of the identical groups of seismic waves, L, at the stations, for a certain epicenter, A. Treskov obtained the value of the velocity of propagation of these waves (Table 11).

TABLE 11

Velocity of propagation of seismic waves, L, according to A. Treskov.

No.	According to differences between moments (of arrival)	Velocity
1	Irkutsk-Tashkent	3.1 km./sec.
2	Irkutsk-Tiflis	2.8
3	Tashkent	2.4

"According to the data of the *Frankfurter Laufzeitkurven,* 1928, the velocity of propagation of the wave, L, is 3.2 km./sec.," adds A. Treskov and points out that he obtained the same value in studying the seismograms, at the Irkutsk station, of the earthquake of September 13, 1928, near Celebes, by comparing the moments of the maxima of the waves reaching the stations along the shortest line with the moments of the maxima [of waves] traveling in the opposite direction. Whipple[50] found directly the following velocity values for the position of the epicenter (Table 12).

TABLE 12

Velocities of propagation of seismic waves according to Whipple.

No.	Place	r	Velocity of waves — initial	Velocity of waves — maximum	Remarks*
1	Irkutsk	950 km.	4.2 km./sec.	3.1 km./sec.	Repsold, m, v, and Milne, m
2	Tashkent	3050	—	3.0	Repsold, m, v, and Milne, m
3	Tiflis	4390	2.8	2.7	Milne, m
4	Jena	5230	2.8	—	Wiechert

*m and v indicate that the pendulums [referred to] are set in the meridian and the prime vertical.

According to Jeffrey's data, Whipple considers it possible to class these waves with the short waves of the Rayleigh type. Assuming the value of 3.2 km./sec. for the velocity of propagation of the waves which produced the maximum deviation, M, we obtain the following value for the moment of explosion, T_0, from the data of the Repsold seismograph (eastern pendulum) (Table 13).

TABLE 13

Determination of the moment of explosion, T_0, according to the seismogram at Irkutsk.

No.	Place	Distance	Δt	$t, Gr.$	T_0
1	Irkutsk	970 km.	5^m0	$0^h\ 20^m1$	$0^h\ 15^m1$

The following table [Table 14] presents a general summary of the results obtained in the determination of T_0 by various methods.

TABLE 14

Summary of the determinations of the moment of explosion at the fall of the meteorite of June 30, 1908.

No.	Source of the determination	Moment of the determination (h m m)	
1	Barograms of 13 Siberian stations	0 16.8 ± 2.2	
2	Sound phenomena of 5 points (Voznessensky)	16.0 ± 2.9	15^m7
3	Sound phenomena of 5 points (Astapowitsch)	15.4 ± 3.6	Irkutsk
4	Seismogram, air-waves	16.2 ± 0.7	
5	Seismogram, seismic waves	15.1	
6	Microbarogram (Slutsk)	15.0	16^m3
7	Barogram of Leningrad station	17.6	
8	English stations	(10.6 ± 3.0)	

$T_0 = 0^h\ 16^m\ 07^s$ G.M.T.

§8. *Determination of the Power and the Work of the Explosion.*—The order of this quantity may be determined, even though crudely, from various data:

1. Acoustic phenomena are recorded all the way from the town Mukhtuy ($\phi = +55°50'$; $\lambda = E.\ 115°\ 30'$, river Lena) and Verkhne-Inbatsky ($\phi = +63°$ [8']; $\lambda = E.\ 88°\ 59'$, Podkamennaya Tunguska) to the Turukhansk taiga (A. Tugarinov) and Enisseysk ($\phi = +58°\ 27'$; $\lambda = E.\ 92°\ 10'$), farther to the Ussinsky region, the Minussinsk taiga, nearly to Lake Baykal (village Chelpanova, near Verkholepsk, $\phi = +54°\ 06'$; $\lambda = E.\ 105°\ 20'$) and Bodaybo ($\phi = +58°\ 00'$; $\lambda = E.\ 123°\ 40'$, river Vitim). This area has the form of a nearly perfect circle, with a diameter of 12°.5 of the arc of the meridian (1350 to 1400 km.); its center lies near the fur-trading station of the Gostorg, Vanovara, on the Podkamennaya Tunguska ($\phi = +102°\ 17'.1$; $\lambda = E.\ 60°\ 20'.3$); apparently there was only one center for the propagation of the sound; on account of its great power, there was no anomalous zone and no silent zone (*e.g.*, at Vanovara, 65 km. from the center of the explosion). Thus, sounds of very low frequency were heard to distances of 700 km.; assuming for the threshold of their perception a power of 100 ergs/cm.^{2} sec. [and] for the altitude of their expansion 50 km., we obtain 10^{17} ergs/sec. as the lower limit of the power of the sound waves; this is obviously only a part of the whole energy of the explosion.

2. The explosion of Krakatoa in the Strait of Sunda, in 1883, was heard at Ceylon (3300 km.) and even at the port of Rodriquez (4900 km.), and the air-wave, as is well known, circled the globe several times; according to this circumstance, the power of the explosion of Krakatoa was several dozen times as great as that of the explosion at the fall of the meteorite of June 30, 1908. During the eruption [of Krakatoa], 18 km.^{3} of dust and steam, 3.6×10^{10} kg. in weight, were thrown up to a height of no less than 20 km.; the work done equalled 7.2×10^{23} ergs; from this fact we may judge the energy developed at the fall of the meteorite to have been of the order of 10^{21} ergs.

3. Some hurricanes [have] produced, on a small scale, destruction similar to [that of] the wave of explosion of the meteorite; the best-known "great hurricane" of October 10, 1780, at Barbados, Martinique, Porto Rico, *etc.*, lifted people and animals into the air and left no foliage on the trees; the hurricane of October 31, 1876 (Chittagans, Bengal, India) carried fragments of buildings a distance of 16 km., *etc.*; the power of such hurricanes, with a velocity of 50 m./sec., is of the order of 5×10^{18} ergs/sec.[VIII] The area devastated by a hurricane is equal to only a few percent of the area of the wind-fallen woods on the rivers Khushmo and Chambe; hence, the power of the explosion at the fall of the meteorite was probably not less than 10^{20} ergs/sec.

4. The imperfect seismic instruments of 1908 (Repsold, Milne, and Bosch, set up in the meridian and in the prime vertical) have made it impossible to calculate, by even the methods of Navarro-Neumann, Jeffreys, or B. Galitzin, the quantity of energy at the epicenter. The earthquake of June 30, 1908, No. 1536,

TABLE 15

The amount of work of various earthquakes.

No.	Place	Date	Work
1	Lisbon	November 1, 1775	1.9×10^{25} ergs
2	San Francisco	April 18, 1906	1.75×10^{24}
3	Messina	December 28, 1908	5.7×10^{22}
4	Sakurashima	January 12, 1914	5.5×10^{22}
5	Ischia	March 4, 1881	1.6×10^{21}

is classed with the minor ones; the energy of such earthquakes is "small to moderate."[IX] By way of example, we list the quantity of work of various well-known earthquakes[IX] (Table 15).

From this information, after having compared the published observations of the tremors of June 30, 1908 (see refs. 12, 15, 16, 19, 20), we may conclude that the energy of the explosion transmitted to the Earth's crust at [the time of] the fall of the meteorite was by no means greater than 10^{22} to 10^{25} ergs and may have been close to 10^{21} ergs.

5. At the [time of the] fall of the meteorite there was observed in [full] daylight from Ilimsk, Kirensk, Nizhne-Ilimsk, Nizhne-Korelinskaya, and other points,[18] a "fiery pillar" above the horizon. Let us suppose that its brightness exceeded the usual brightness of the full Moon, but that its brightness was less than the brightness of the Sun; in this assumption we shall be not far from the truth, since, on the Podkamennaya Tunguska, a reflection was seen in the windows facing northward. At a distance of 500 km., the visible brightnesses, -14^{M} and -26^{M},* correspond [respectively] to a light-power of 2×10^{11} and 1.3×10^{16} international candles.[X] [The formula used by Astapowitsch to obtain these results, *viz.*, $\log J = -0.4\, m + 2 \log \Delta + C$, where J is the intensity of the light in international candle-power, m is the apparent stellar magnitude, Δ is the distance of the observed light-source in km., and C is a constant, is an immediate consequence of the classical brightness-magnitude relation. Thus, if objects of candle-power, b_m, b_n, have apparent magnitudes, m, $n = 0$, when seen from a distance of 1 km., we have: $\log b_m = -0.4\, m + C$, where $C = \log b_n$. The candle-power, J, of an object which appears of magnitude m as seen from a distance of Δ km. is evidently $\Delta^2 \times b_m$. Hence, $\log J = \log b_m + 2 \log \Delta$, which is the formula of Astapowitsch. The value of the constant, C, in this formula is about 0.26, as may be deduced, *e.g.*, from data given by Drude, *Lehrbuch der Optik*, 445, 1900.] For temperatures of 2000° [C.] and more, the emission of light is about 10 lumen/watt [*cf.* Coblentz, *Bull. Bur. of Standards*, **14**, 264, 1918]; the lower limit of the power of the explosion lies, accordingly, between 2×10^{19} and 10^{24} ergs/sec.

6. Apparently, we may assume that the region of wind-fallen woods occupies approximately 8,000 km.^{2}; taking the mean forest technical indexes [indices] of this region, we may assume that the average number of trees (pine and larch) on 1 hectare [2.47 acres] is not less than 100, [and that they are] of an average diameter of 20 cm. or more. The trees are either uprooted or broken down. From the [theory of the] resistance of materials, we know that the bending moment, M_z, in relation to the moment of inertia, I, and the distance, [e], of the extreme fiber from its neutral axis, is expressed thus:

$$M_z = pl = \frac{I}{e} K_b ,$$

where p is the force applied to the end of the lever which is fixed at one end, l being the length of the arm, and K_b is the tension in kg./cm.^{2} In the case of a circular cross-section (for which $I = \pi d^4/64$, $e = d/2$) of a green pine-tree, breaking begins for $K_b \geqslant 700$ kg./cm.^{2} Assuming that the pressure of the air was received by the leafy top of the tree, with the length of the trunk $l = 10$ m., we obtain $p = 550$ kg. [The value of this result is questionable. The bending moment, M_z, which will break a tree cannot be calculated from the *flexure formula* by substi-

*[The apparent visual magnitude of the full Moon is equal more nearly to −12.6 and that of the Sun, to −26.7.—Ed.]

tuting for K_b the ultimate tensile strength of the wood of the tree. The flexure formula is valid only when the distribution of fiber-stress is *linear*, as is the case only when the unit fiber-stresses are not greater than the elastic limit of the material. *Cf., e.g.,* Maurer and Withey, *Strength of Materials,* 2nd Ed., 152, §98, 1935.] If we assume a general effective area of pressure of several m.^{2}, we obtain from the expression, $p = \frac{1}{8}u^2$, a value of several dozen m./sec. for the velocity of the air-masses; *i.e.,* a velocity of the order of [those of] ordinary hurricanes, near even the outer limits of the wind-fallen woods, *i.e.,* more than 50 km. from the center of the explosion. Let us suppose that the force [p] acted on the upper part of the tree and broke the tree, causing the top to bend 5 m.; then the work of blowing down 8×10^7 trees was 4.4×10^{21} ergs, and the whole energy of the explosion must have been greater, since part of it was lost in the atmosphere.

7. Whipple gave an example of calculating the energy of the air-wave from the microbarograms of England. He obtained [a result equal to] 3.2×10^{20} ergs. Following his example and using the microbarogram at Slutsk, we found the energy to have been 0.5×10^{20} ergs. In Table 16 is given a summary of the results.

TABLE 16

Energy of the explosion at the fall of the meteorite of June 30, 1908.

No.	Method	Power	Work
1	Audibility limit of sound phenomena.....	$>10^{17}$ ergs/sec.	—
2	Comparison with explosion of Krakatoa...	—	$\leqslant 10^{21}$ ergs
3	Comparison with hurricanes.....	$>5 \times 10^{20}$	—
4	Comparison with earthquakes.....	—	$\leqslant 10^{21}$
5	Absolute luminosity of explosion.....	2×10^{19} to 10^{24}	—
6	Wind-fallen trees.....	—	$>4.4 \times 10^{21}$
7	Energy of air-waves (Slutsk).....	—	$>0.5 \times 10^{20}$
8	Energy of air-waves (England, by Whipple)	—	$>3.2 \times 10^{20}$
			Mean Work = 10^{20} to 10^{21} ergs

§9. *Physical Conditions of the Fall.*—1. The brightness of the meteorite during its flight was apparently very considerable: At the village Znamenskoye, it seemed as though "a piece broke away from the Sun," was "brighter than the Sun," had a "blinding head" (Kirensk[15]), "one could not look [at it]" (*id.,* ref. 28), "considerably larger than the Sun" (I. Kokorin, at Mursky Porog); assuming that its visible brightness at a distance of 200 to 300 km. was undoubtedly greater than the brightness of the full Moon (—14^M), but less than that of the Sun (—26^M), we find that the "absolute" power of the light was of the order of 10^{10} to 10^{16} international candles. No bolide known to the author has had such light power [brilliance]. Arago[XI] mentions that, in 91 B.C., there was a bolide exceeding the Sun in brightness; in China, on September 26, 307 [A.D.], a bolide was observed "like the Sun," with a tail; and the famous bolide of Halley, on March 19, 1718, was as bright as the Sun, and the full Moon became invisible; it was seen at a distance of 960 km. and had a gaseous envelope 2560 m. in diameter. The explosion of the meteorite of June 30, 1908, was still brighter, since on the Angara and the Lena[I] a reflection was seen in the windows facing north; *i.e.,* according to the well-known physiological law, the brightness of the meteorite had to exceed one percent of the brightness of the Sun in order to be noticeable. E. Sarychev (Kansk) estimated the diameter of the bolide to be "about half of the Moon"; this [estimate] gives $B = 5/10$ to 10^5 [*sic*] international candles for the brightness of

1 cm.^{2} of the gaseous envelope; B is usually of the order of 10^{-3} to 10^{-4} for bolides and meteors.[X]

2. The color of the meteorite during its flight (*i.e.*, the color of its gaseous envelope) was very generally characterized as "fiery" (village Yarskaya, village Chechuyskaya, Kirensk, also Vakulin and Ponomarev of Nizhne-Ilimsk), as a "fiery conflagration" (S. Semenov, Vanovara), [and as] "an azure light" (I. Kokorin, of Mursky Porog); it shone "with a white, azure light" (Nizhne-Korelinskaya). Evidently the meteorite attained a very high temperature; this fact points to a very great geocentric velocity within the Earth's atmosphere, exceeding, in the opinion of the author, 30 to 40 km. [/sec.]; slower meteorites, as we know, are yellow and red in color. One observation ("a red ball"), from Kirensk, contradicts all the others.

3. The bolide appeared spherical in form to distant observers: "a fiery ball" (at the village Yarskaya, at Kirensk, at the village Voroninaya, at Nizhne-Ilimsk); "of a circular form" (Kansk); according to other reports, it appeared cylindrical in form (Nizhne-Korelinskaya); "like a log" (Nizhne-Ilimsk). If we accept the estimate of E. Sarychev (Kansk) that it was "about half the Moon in dimensions," *i.e.*, 16′, then the extreme values of the linear diameter of the gaseous envelope were 0.5 to 5.5 km. I. Kokorin (Mursky Porog) states "larger than the Sun," *i.e.*, correspondingly more than 0.5 to 2.0 km., for the extreme values of the azimuth of the flight [*sic*]. Bolides are usually 0.1 to 1.5 km. [in diameter].

The explosion was observed from many points in the form of a vertical fountain: "a fiery pillar," "in the form of a spear" (Kirensk); "changed into a fiery pillar and disappeared in a moment" (Nizhne-Ilimsk); there were "fiery pillars" (trading-station Teteria[16]); at the place of the explosion was formed, after a while, "a huge cloud of black smoke" (Nizhne-Korelinskaya); "there appeared . . . a dense cloud" (Nizhne-Ilimsk); "there arose clouds of black smoke" (Kokoulin); a rising "cloud of smoke" (Vakulin, Nizhne-Ilimsk); "smoke appeared" (I. Ponomarev, at the same place). At a distance of 450 to 500 km. from the place of explosion, the lowering of the horizon amounts to 16 to 20 km.; hence, it must be granted that both the pillar of the explosion and the "black smoke" rose to a height considerably greater than 20 km. It is possible that the products thrown out by the explosion were one of the causes of the anomalous morning and evening glows from June 30, to July 2, 1908,[50] as was the case after the eruption of Krakatoa and other volcanoes; the silvery clouds of June 30, 1908, moved from Siberia westward. One need not think that the "black smoke" was the product of the scorching of the wooded area—this phenomenon is very frequent in connection with the fall of meteorites.

4. Very interesting were the thermic phenomena observed at Vanovara at the time of the fall: "it got so hot that it was impossible to sit [still]; it almost burned the shirt off my back" (S. Semenov); P. Kossolapov: "something, as it were, intensely burned my ears";[20] the author knows of only a single report of an analogous kind, [one] in connection with the flight of the bolide on March 1, 1929, over the Tarsk district in western Siberia, when one observer reported that "she felt on her face the warmth" of the passing bolide. If that report was true, then this problem requires special examination.

5. The Tungus meteorite of June 30, 1908, according to all data, moved through the atmosphere with very great speed; all visual estimates corroborated this conclusion: "a huge object rushed past" (N. Ponomarev, Nizhne-Ilimsk); "it flew past from south to northwest"; "a fiery object flew past (from the south)"

(I. Kokorin, Mursky Porog); "a swiftly-flying object" (E. Sarychev, Kansk); *etc.* Unfortunately, no precise estimates were made and such reports as, "it lasted ten minutes," are common exaggerations (see §2, *ante*). The proximity of the meteorite's radiant to the apex of the Earth (see hereafter) confirmed the fact as did likewise the extremely high degree of incandescence of the gaseous envelope that surrounded the flying meteorite. The intense and uninterrupted charring [char], which, in thin layers, covered the trees of the central region of the explosion, also attested to the brevity of the action of the wave of very hot air that followed the explosion of the meteorite and that resulted from the transformation of kinetic into thermic energy. At the velocities $v = 10$ to 100 km./sec., 1 g. gives 0.5×10^{12} to 0.5×10^{14} ergs, in case of complete arrest; whence the maximum mass, with the total [amount] of energy given off, $E = 10^{20}$ to 10^{24} ergs, will be [comes out equal to] 2 to 200 [metric] tons. [The mass lies between 2 and 2,000 metric tons unless only the lower bound for E is used in the calculations.] For velocities of 50 km./sec. and higher, the upper limit is 8 tons; Whipple gives 12 tons.

§10. *The Trajectory of the Flight and the Radiant of the Meteorite of June 30, 1908.*—The insufficiency of observations does not permit us to determine with the precision desired, the position of the trajectory of the meteorite of June 30, 1908, in the atmosphere. On the basis of indirect considerations (see *ante*), and a series of direct observations, L. Kulik, S. Obruchev, and I. Astapowitsch have inferred that the flight occurred from south to north, across the line of the Siberian railroad, since the bolide was observed to the east of Kansk (E. Sarychev, "from south to east"), to the east of the village Znamenskoye (where it seemed as though "it broke away from the Sun and flew to the north"), but to the west of Ilimsk, Ust-Kut, Lower Ilimsk, Lower Korelinskaya, and Kirensk. This inference makes the limits of the azimuth 164° to 206°, [as measured] from the north. The trajectory was very slanting ("horizontal," "quite inclined." in Kirensk; it descended "inclined to the horizon" at Lower Ilimsk); this fact is confirmed also by the great length of the series of points of observation of the meteorite from south to north —at least from Kansk to Vanovara, or about 550 km.; therefore, assuming even the greatest [known] height [h km.] of the flashing-up [appearance] of fast bolides (equal to 150 to 200 km.), [we find that] this [height] gives, as the greatest value of the angle of inclination, I, of the trajectory to the horizon, 18° to 24°.

[If we assume: (α) that the point of appearance, A, was in the zenith of a point, K, on the surface of the Earth, at a distance of d km. from the point of fall, F, and (β) that the visible path from A to F was rectilinear, we find that $I(d, h)$ has approximately the following values: $I\,(550, 150) = 13°$; $I\,(550, 200) = 17°$. If, in addition to (α) and (β), we suppose (γ) that the curvature of the Earth between F and K is negligible, then $I\,(550, 150) = 17°$; $I\,(550, 200) = 22°$; while $I\,(450, 150) = 18°$; and $I\,(450, 200) = 24°$. It appears, therefore, that Astapowitsch worked under assumptions (α), (β), and (γ), with $d = 450$.]

The lower limit of I [is] about 0°, since the zenith-attraction for swift meteorites with the radiant near the apex is small. However, in the case of a very small [value of] I, the meteorite, passing through perigee near Vanovara, would have again receded along an hyperbola deformed by the resistance of the air, as actually happened, *e.g.*, in the case of the bolide of September 5, 1868, which, in 17^s, flew a distance of 1,500 km. through the atmosphere over Serbia, Austria, and France.

[Astapowitsch next calculates a lower bound, B, for I, on the assumption that the geocentric orbit of the Tungus meteorite was hyperbolic. His discussion can be simplified and extended as follows: Let the transverse axis of the orbit, with

perigee at F, near Vanovara, be taken as the polar axis of a system of reference (r, θ), in which θ is the true anomaly. Then, at any point, M, on the orbit, the following familiar equations are valid:

(1) $$v \sin \psi = \frac{\mu}{h}(1 + e \cos \theta); \qquad v \cos \psi = -\frac{\mu}{h} e \sin \theta.$$

In (1), v is the geocentric velocity at M, $\psi = \pi/2 - I$ is the angle from the velocity-vector to the radius-vector drawn from M to the focus, and e is the eccentricity. From (1),

(2) $$\tan \psi = \operatorname{ctn}(2\pi - \theta) + e^{-1} \csc(2\pi - \theta),$$

where, for $d = 550$, $(2\pi - \theta) = (550/6370)$ radians $= 4^\circ.9$. Equation (2) shows that the values of ψ corresponding to the maximum-possible velocity-range (for which $\infty > e > 1$) satisfy $85° < \psi < 87^\circ.5$. Hence, always, $2^\circ.5 < B < 5°$. If attention is limited to a sub-range of velocities, then to obtain bounds for ψ, from the convenient formula (2), we need determine only the sub-range of eccentricities corresponding to the velocities considered. Since the inequalities $I < 24°$, $\psi < 87^\circ.5$ insure that $0.8345 < \sin^2\psi < 0.9990$, this sub-range of eccentricities can be found with all necessary precision by use of the standard formula for e^2 in terms of v, $\sin^2\psi$, and the parabolic velocity, $u = 11.18$ km./sec. If we assume with Astapowitsch, in particular, (δ) that 30 km./sec. $< v <$ 80 km./sec., then (2) shows that $85° < \psi < 85° 28'$, and hence that $4° 32' < B < 5°$. Under the assumptions (α), (β), (γ), and (δ) of Astapowitsch, we may conclude, therefore, that if the value of I at F, near Vanovara, had been less than approximately 5°, the Tungus meteorite would not have fallen.] In 1929, the author did not deny the possibility of this event, but the study of the new data of 1930-1933 entirely excludes it. Thus, the trajectory of the meteorite was inclosed along the azimuth within the limits of the sector 164° to 206° north, and, in inclination, within 4° [5°] to 24°; to determine the direction more exactly is apparently impossible.

Assuming that the moment of the explosion, $T_0 = 0^h 16^m 1$, disregarding the length of the flight through the atmosphere, and knowing that the trajectory was inclosed within the limits 164° to 206° in azimuth and 5° to 24° in altitude, we obtain for the center of the explosion [F], ($\phi = +60° 54'$; $\lambda =$ E. $101° 54'$), the following coördinates (Table 17), which limit, on the celestial sphere, the position of the radiant. [Only coördinates in error by more than 1° have been corrected in Table 17.]

TABLE 17

[Coördinates limiting the position of the radiant for the center of the explosion of the meteorite.]

Azimuth	[A]	164°	206°	164°		206°
Altitude	[h]	5	5	24		24
[Right Ascension]	α	42	355	43	[38]	360
[Declination]	δ	—23	—21	—4		—2

This region lies entirely within the constellation of the Whale [*Cetus*], and it appears that, in the known catalogs of meteor streams and of bolides, no noticeable radiant for this region, at this period [time], is indicated; however, it is well known that the radiants of meteorites are usually in no way connected with other radiants.

The elongation from the apex of the radiant of the meteorite of June 30, 1908, lies within the limits 6° to 45°; the radiant lay to the south of the ecliptic, a short distance away from it. Thus, the meteorite [had] passed perihelion and met the Earth at the ascending node of its orbit, which was comparatively little inclined to

the ecliptic. Its orbit was [probably] hyperbolic, the movement in the orbit having been reversed [retrograde].

This necessarily concise survey of the remarkable meteoritic phenomenon that occurred at $0^h 16^m$ [G.M.T.], June 30, 1908, is supplemented by [those] references accessible to the author. It is hardly to be expected that our generation will for a second time be witness to a similar grandiose phenomenon.

In conclusion, the author expresses his thanks to the Academician V. Vernadsky and to Professors A. Voznessensky, L. Kulik, A. Ovchinnikov, and A. Treskov.

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Leningrad-Stalinabad, U. S. S. R., June 30, 1933

[*Concluded.*]

Errata in the October Issue

P. 434, §1, 8th line of the section: "with its maximum phase at $^h 20^m1$," should read, "with its maximum phase at $0^h 20^m1$."

P. 436, §1, the last line on the page should read as follows: "*Meteorites*, p. 24, 1927.—ED.] in the former Kiev government and which is now in."

VARIABLE STARS

Variable Star Notes from the American Association of Variable Star Observers

By LEON CAMPBELL, Recorder

Variability of BF Cygni: The variability of BF Cygni, 192029, was detected by d'Esterre in 1914. He found an irregular variation in light between the photographic limits of magnitude 9.4 and 11.2, which was later confirmed by Hoffmeister. D'Esterre also described the color of the star as pale red when it was faint. These facts are not inconsistent with each other and doubtless little would have been done on the star had it not been for a fortunate accident.

Mr. W. C. Miller, when examining a Mount Wilson plate taken on August 23, 1940, found near to the spectral image of BF Cygni a bright line object which could not be found on any other plate, even on one taken two weeks later (*Harvard Announcement Card* 535). Dr. P. W. Merrill notified the Harvard Observatory of the presence of this bright line object and also remarked on the variability

of the bright lines in the star BF Cygni. Dr. Dorrit Hoffleit could find no evidence of a variable star in the vicinity of BF Cygni, so the appearance of this short-lived, bright-line object still remains an unsolved mystery. BF Cygni itself, on the other hand, has proved to be quite a remarkable star.

From observations made on Harvard plates, extending almost without interruption over the last 50 years, Dr. L. Jacchia has gathered together some very interesting facts concerning BF Cygni. He has found that the variation is of a semi-regular character, at times with a semblance of periodicity of about 754 days, broken by an interval of complete irregularity. From 1890 to 1921 the light curve shows variations, or waves, of quite diverse shape, with average amplitude of just over a magnitude and with a period of 754 days, as mentioned above. The maxima were usually broad, with irregularities, while the minima were more narrow, at times even approaching the form of the light curves of eclipsing variables. The 754-day wave appears to be superimposed upon a much longer wave, approximately 25 years in length. The total amplitude of the star, from brightest maximum to faintest minimum, is four magnitudes, 9.3 to 13.4. After 1922 the variation became very erratic with extra waves which nearly masked the 754-day period. From 1928 to 1934 the star remained nearly constant in light, only decreasing about a tenth of a magnitude in the six years. In 1935 the semi-regular variations reappeared with renewed energy, and, curiously, quite in phase with the variations noted in the years 1890 to 1921, just as though the intervening irregularities had not altered the rythmn of the star's variation.

In spite of d'Esterre's estimate that the star was of a pale red color when faint, it should not be considered a red star. Although the color index is certainly positive, it does not exceed half a magnitude. On Harvard plates, according to Mrs. M. W. Mayall, the spectrum appears to extend far into the violet, approximately as a B-type spectrum would do. Moreover the star is included in the Merrill-Burwell catalogue of Be and Ae stars with the designation Bep. The bright lines identified by Merrill belong to hydrogen, helium, iron, and oxygen. There is also present the nebular line 4363 (O III), which shows considerable variation in intensity. Thus, according to the distribution of energy in the continuum and the high excitation lines, the star is intrinsically what could be called a "blue" star. It is probable that the reddish color noted by d'Esterre is due to the great intensity of the red Hα line and also to space absorption, since the star lies in the plane of the Milky Way.

Mrs. Mayall states that the bright lines are brightest when the star is faint, and that they almost disappear when the star is at maximum. This, according to Dr. Jacchia, seems to be a common characteristic of all early-type variables with bright lines, *i.e.*, novae, U Geminorum, P Cygni, and Be stars, such as Gamma Cassiopeiae.

BF Cygni is, as far as we know, a unique object, since no periodicity has ever been found in any other Be star. On the other hand, light variations of only a very few Be stars have been investigated thoroughly and it is more than probable that a survey of such objects will reveal additional stars of the same type as BF Cygni.

Variables in MWF 189: The examination of another Milky Way Field (No. 189, R.A. $17^h\,39^m$, Decl. $-26°.2$) has just been completed by Miss H. H. Swope at Harvard Observatory and some interesting statistical facts are revealed in her report. The field is centered on the galactic equator at longitude 330°, in the heart of the Southern Milky Way. She has discovered therein 86 new variables, which, added to the 32 already known there, brings the total up to 118. They are grouped

as follows:

	No.	%		No.	%
Eclipsing	61	52	Short-Period	4	3
Irregular	20	17	Cluster	4	3
Long-Period	15	3	RV Tauri	2	2
Cepheid	6	5	SS Cygni	1	1
Nova	5	4			
			Totals	118	100

Periods have been derived for most of the new variables and for many of these, light curves with coördinates are given. Mean maximum magnitude for the eclipsing variables is 12.9 and for the long-periods, 13.8; mean median magnitude for Cepheids is 11.0 and for Cluster variables, 13.7. Several of the "Irregulars" have large color indices, of the order of three magnitudes, indicating their extreme redness.

Among the eclipsing variables is one, SVS 457 (1726*21*), which evidently has a very long period, 6000 days or longer.

The center and preceding half of this field is covered by a dense cloud of obscuring matter and for this reason the abundance of variable stars here is relatively small; 25 to the north of the galactic equator and 93 to the south. The novae abound on the border of the south following corner of the field, on the edge of the Sagittarius star cloud. The Cepheid variable, HV 10302, with a period of 5.7 days and a median magnitude of 14.2, has a color excess of more than two magnitudes.

The SS Cygni-type variable, HV 9175, has a range of three magnitudes (13.5 to 16.5) and exhibits cycles of 20 and 30 days; its light curve resembles that of Z Camelopardalis. The periods of the two RV Tauri-type stars are 45.28 and 175.2 days. For KW Sagittarii there are indications of cycles of 670 days, with a light curve resembling that of Z Andromedae.

Magnitudes of Currently Observed Novae: A half dozen novae continue to be observed systematically by the A.A.V.S.O. Nova Persei, 1901, appears still to vary in an irregular fashion, between magnitudes 12 and 13. Nova Pictoris, 1925, is slowly decreasing at the rate of about 0.2 of a magnitude per year; at the present time it is at magnitude 9.9. Nova Herculis, 1934, is steadily fading away; on October 1 it had dropped to magnitude 10.9, a drop of about a magnitude in a year. Nova Aquilae, 1918, appears to oscillate irregularly, with considerable scatter in the estimates, between magnitudes 10.5 and 11.8. Nova Lacertae, 1936, is gradually diminishing in light, having recently reached magnitude 14.0.

The two recurrent novae, T Pyxidis and RS Ophiuchi, are both at their faint stages, magnitudes 14, and 11 to 12 respectively.

If we should extrapolate from the 12 and 18 year intervals between outbursts of T Pyxidis—maxima ocurred in 1890, 1902, and 1920—we would expect a fourth maximum during the next few years. For RS Ophiuchi the observations appear to be too consistent to doubt the reality of a yearly cycle between maxima which has appeared in the years following the star's last return to normal minimum light.

Nova (DO) Aquilae, 1925: In a recent contribution to the *Astrophysical Journal,* B. Voronstov-Velyaminov calls attention to the close similarity in form of light curve of Nova (DO) Aquilae to that of Nova (RR) Pictoris, both discovered in the same year, 1925. Both are defined as "slow" novae, that is they spent a long time after the initial outburst in attaining greatest brilliance, followed by marked oscillations over a protracted maximum. Little is known of the actual rate of the initial outburst but it may well be assumed to be rapid. The question has been raised in connection with RR Pictoris as to whether the bright maximum ob-

served three days after discovery was the principal one, or if maximum brightness occurred on or about the time when the star was observed at the third magnitude, some 55 days previous to actual discovery.

DO Aquilae, for a time referred to as Wolf's variable and not as a nova, was not too completely observed at maximum, but it is known that it remained at an unusually flat maximum for about eight months. During this interval of time there was a gap in observations covering about two months.

The spectral behaviour of DO Aquilae and RR Pictoris is very similar and, when the light curves are superimposed so as to bring into coincidence the dates when the spectra were identical, there is a remarkable similarity in form. The two novae differed by about six magnitudes in their brightness at maximum, RR Pictoris, the brighter, having reached nearly to the first magnitude. Both novae exhibited marked oscillations during maximum brightness. The late history of both is nearly identical—a very gradual decline towards minimum, at approximately the same rate. The author concludes that there may have been a sharp bright maximum of DO Aquilae during the interval of two months when the nova was not observed, this conclusion being based on the resemblance between the two novae at other phases.

Observed Maxima of SS Cygni-type Variables, 1939: A few years ago the A.A.V.S.O. observing list of SS Cygni-type variables, including stars of the so-called Z Camelopardalis-type, was considerably extended to include those for which additional data were greatly needed. Many of these stars are faint, especially at minimum, and only the maxima, in whole or in part, can be observed except in the very largest telescopes. With the thought that times of maxima would be of value in discussing periods (or perhaps cycles is the better term) observed dates are listed below in Julian days, together with the approximate length of the cycles in days. For convenience the first three digits of the Julian day number (242) are omitted. These dates are to be considered, for many stars, only approximate; some may be in error by a day or two, because of the scarcity of observations.

005840 RX Andromedae

9281	..	9484	16	9552	4
9380	..	9497	13	9559	7
9397	17	9512	15	9568	9
9413	16	9516	4	9582	14
9438	..	9523	7	9586	4
9454	16	9533	10	9596	10
9461	7	9543	10	9603	7
9468	7	9548	5	9634	..

020356 UV Persei

9401	..

020657 TZ Persei

9272	11	9399	20	9551	17
9287	15	9457	..	9572	21
9306	19	9472	15	9591	19
9341	..	9492	20	9610	19
9355	14	9516	24	9632	22
9379	24	9534	18		

054705 CN Orionis

9268	18	9335	18	9567	18
9284	16	9351	16	9584	17
9300	16	9371	20	9616	..
9317	17	9549	..	9630	14

060547 SS Aurigae

9315	40	9492	66	9622	67
9426	..	9555	63		

074922 U Geminorum

9312	..	9494	..

080362 SU Ursae Majoris

9278	15	9365	19	9569	15
9304	26	9391	26	9587	18
9312	8	9403	12	9601	14
9327	15	9416	13	9611	10
9346	19	9554	..		

081473 Z Camelopardalis

9281	..	9444	30	9552	20
9330	49	9484	40	9581	29
9371	41	9512	28	9605	24
9394	23	9532	20	9621	16
9414	20				

094512 X Leonis

9284	30	9359	27	9560	..
9307	23	9384	25	9581	21
9332	25	9409	25		

184137 AY Lyrae

9263	..	9425	..

195109 UU Aquilae

9247	..	9344	..	9404	60

195377 AB Draconis

9276	23	9420	24	9528	15
9286	10	9435	15	9542	14
9312	26	9467	..	9552	10
9328	16	9487	20	9569	17
9349	21	9500	13	9581	12
9369	20	9513	13	9596	15
9396	27				

213843 SS Cygni

9270	50	9411	57	9595	46
9307	37	9483	72	9627	32
9354	47	9549	66		

220912 RU Pegasi

9375	..	9468	93	9558	90

Observers and Observations received during the month of September:

Observer	Var.	Obs.	Observer	Var.	Obs.
Albrecht	15	21	Kanda	3	7
Ball, A. R.	28	38	Kearons	53	81
Ball, J.	68	75	Kelly	13	15
Bates	1	4	deKock	80	522
Blunck	47	63	Kouts	17	17
deBois Blanc	7	7	Livingston	29	29
Bouton	23	41	Lovinus	5	5
Britzelmayer	5	14	Mason	14	23
Buckstaff	21	156	Manlin	4	4
Carpenter	7	7	Martin	2	4
Chandra	55	78	Millard	12	27
Chilton	4	4	Murphy	23	30
Cilley	19	53	Neale	7	7
Cousins	47	151	Parks	19	30
Dafter	8	33	Peltier	32	98
Davis	5	8	Prinslow	19	19
Diedrich	1	2	Purdy	8	8
Economou	22	62	Rosebrugh	10	82
Escalante	35	41	Ryder	4	4
Ferguson	14	16	Saxon	28	29
Fernald	142	433	Schoenke	1	1
Ford	8	8	Schmidt	8	9
Forrester	5	5	Sill	71	71
Gregory	111	153	Smith, F. P.	12	18
Griffin	8	8	Snyder	2	2
Halbach	92	265	Stahr	11	11
Harris	23	23	Taulman	8	8
Hartmann	128	182	Topham	40	40
Hildom	15	29	Townsend	10	10
Holt	34	34	Walton	10	14
Howarth	15	34	Webb	17	17
Huffer	12	12	Yamada	10	16
Irland	11	11	Yamasaki	14	14
Jones	49	80			
			Total		3400

Erratum: Popular Astronomy, October, 1940, page 446, lines 17, 18, for *for the Wolf-Rayet star, 0.27A (9.70)* read *for the Wolf-Rayet star, 0.16A (5.8 ⊙) and for the B1 star, 0.27A (9.7 ⊙).*

Notes from Amateurs

The Herschel Astronomical Club

The Herschel Astronomical Club of Fall River began its sixth season on October 4 with a meeting at the home of the secretary. An illustrated talk, which described the characteristics of several comets, beginning with one described by

Seneca and ending with Halley's, was heard by the members. At the next meeting, Winifred Kearons will present a résumé of her work on variable stars.

Mr. Samuel R. Parks was elected president of the club for the fifth time. It is planned to meet once in every six weeks.

FRANK J. KELLY, *Secretary.*

Fall River, Massachusetts, October 8, 1940.

Astronomical Society of Nevada

On Wednesday, September 25, Mr. Carl E. Wells addressed the Astronomical Society of Nevada on the topic, "Why Nevada Should and Can Have a Public Observatory."

Mr. Wells offered to give the Society a fine 12½-inch mirror together with all the necessary optical parts for a Newtonian telescope, if the Society would build the telescope mounting and provide for its housing. The Society accepted the offer and a committee is now at work on plans for a modern mounting with electric drive and all necessary refinements for visual and photographic use.

On Wednesday evening, August 7, the Society held its sixth annual telescope meeting. The earlier telescope meetings were held on a hill in the northern part of the city of Reno, but the last three have been combined with picnics at sites high in the mountains surrounding the city. The last meeting, as well as the preceding one, was held on the shoulder of Mount Rose at an altitude of 8000 feet above sea level.

Again, as was the case last year, the heavens presented a magnificent spectacle impossible to imagine by one who has not seen the night sky from high altitudes. Because of the absence of planets in the evening sky, special attention was given to constellation study, although the telescopes were not idle. About forty people, members of the society and their families, were present.

The Astronomical Society of Nevada holds approximately monthly meetings throughout the year, discussing, if possible, astronomical topics of current interest. Thus, in the October meeting, a discussion of the planet Mercury and the coming transit of Mercury, and of comet Cunningham will be in order. On occasion, astronomers from coast observatories are called upon for addresses.

The officers of the Society are: G. Bruce Blair, President, John L. Carlson, Vice President; Moreton J. Thorpe, 17 North Virginia Street, Reno, Nevada, Secretary-Treasurer, and Mrs. C. H. Luke, Chairman, Program Committee.

University of Nevada, Reno, Nevada, October 1, 1940.

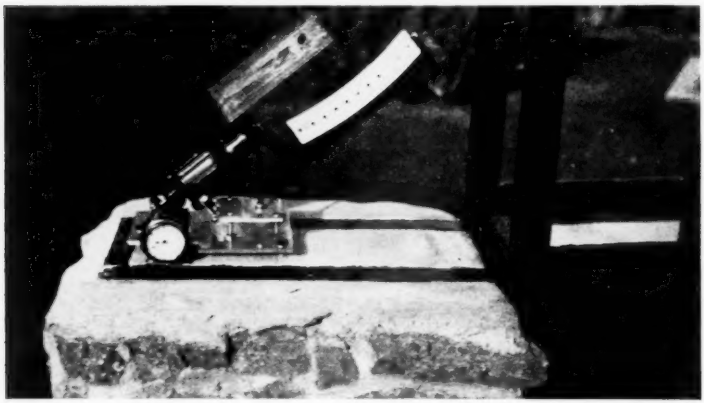
A Sun-Clock

A sun-clock has been recently constructed by the writer of this article which goes somewhat farther than the usual sun-dial inasmuch as an analemma automatically makes the correction for the equation of time so that mean solar time is obtained.

A horizontal shaft carries a single thread steel worm, one end of the shaft being directly connected to the setting knob of an alarm clock from which all the movement has been taken except the parts which gear the motion of the hour hand. The worm meshes with a 24-tooth bronze worm gear which is attached to the lower end of a polar axis so that 24 turns of the horizontal shaft will turn the polar axis once. A Ford pump assembly was used to make the polar axis.

At the outer end of the polar axis is attached a piece of 2½-inch band iron shaped so that one branch carries a plus 4 lens, stopped down to one-eighth of an

inch in diameter, and the other branch carries an analemma curved to a radius of 10 inches and held 10 inches from the lens. The analemma is drawn with India ink on a sheet of aluminum and marked with the degrees of the sun's declination. Opposite each degree mark is given the date of the sun's crossing.



A Sun-Clock

By means of a knurled knob the horizontal shaft is rotated until the sun's image (about an eighth of an inch in diameter) is bisected by the appropriate branch of the analemma and the time is read from the clock dial and hands. The instrument gives the time to about a minute and the approximate day of the year. Final adjustments have not yet been made but it is doing pretty well now.

The sun-clock is mounted on a stone pier in the yard and is covered by a glass and wood cover. The cover tilts back on a rest when the instrument is being used.

Berthoud, Colorado, October 10, 1940. John Bunyan.

General Notes

The Rittenhouse Astronomical Society held its monthly meeting on Friday, October 11, in the Lecture Hall of the Franklin Institute in Philadelphia. The speakers were Wagner Schlesinger, Director, and Dr. Roy K. Marshall of the Fels Planetarium. Transits in general, and the one of Monday, November 11, in particular, were discussed.

The Royal Astronomical Society of Canada is celebrating the 50th anniversary of its founding. The issue of *The Journal of the Royal Astronomical Society of Canada* for September is designated "The Jubilee Number." It contains an extended historical account of the growth of the Society. There is also an historical paper on the founding of the Toronto Magnetic Observatory. The Society having started in Toronto has extended its activities to centers in Ottawa, Peterboro, Hamilton, Winnipeg, Regina, Guelph, Victoria, Montreal, London, Vancouver, and Edmonton.

One feature of the Jubilee celebration was the recognition of the work of Professor C. A. Chant in promoting astronomy in Canada. A special medal designated as the Chant Medal has been struck, which is to be awarded not more often than once a year to an amateur astronomer, resident in Canada. The award is to be made on the basis of the value of the work done in astronomy and closely allied fields. The Chant Medal committee for the year 1940-41 consists of: H. R. Kingston, Chairman, R. M. Stewart, J. A. Pearce, and R. K. Young.

The Francis C. McMath Memorial Telescope of the McMath-Hulbert Observatory

On October 12, 1940, simple and informal dedicatory exercises were held at Lake Angelus, and a bronze tablet was unveiled on the pier of the new Francis C. McMath Memorial Telescope, a beautifully mounted reflector of 24 inches aperture. The invited guests were the staffs of the University of Michigan Observatory and the McMath-Hulbert Observatory, as well as the donors who have made possible the construction of the new instrument.

The late Francis C. McMath, who died in 1938, was one of the three founders of the McMath-Hulbert Observatory. One of the keenest interests of his later years was the work that was being done with the original telescope of the observatory, a 10½-inch pyrex reflector, and more particularly its applications to astronomical motion picture photography and the study of the solar prominences. A more powerful instrument of the same general type was deemed to be a most fitting memorial to one who had taken such an interest in this field of work.

While the 24-inch reflector utilizes the pier, dome, and some portions of the mounting of the former 10½-inch, it is for all practical purposes an entirely new instrument. The 24-inch primary and the secondaries of 50 feet and 100 feet effective focal length are of pyrex, and were figured by Perkin and Elmer. The design of the unusually efficient mounting is due to Director Robert R. McMath.

Book Reviews

Publications Received.—The publishers of POPULAR ASTRONOMY hereby acknowledge the receipt of the following named publications and express their great appreciation of the courtesy shown on the part of those who have sent them.

Contributions from the Mount Wilson Observatory:

No. 622. "Spectral Energy-Curve of the Sun in the Ultraviolet," by Edison Pettit.
No. 623. "The Wolf-Rayet Spectroscopic Binary HD 193576," by O. C. Wilson.
No. 624. "Physical Characteristics of the Wolf-Rayet Stars," by O. C. Wilson.
No. 625. "Relative Populations of 2^1S and 2^3S States of Helium in the Orion Nebula," by O. C. Wilson.
No. 626. "Some Corrections to Dreyer's Catalogues of Nebulae and Clusters," by Dorothy Carlson.
No. 627. "Radiation Measurements on the Eclipsed Moon," by Edison Pettit.

Contributions from the McDonald Observatory:

No. 9. "Emission Nebulosities in Cygnus and Cepheus," by Otto Struve and C. T. Elvey.
"Observations Made with the Nebular Spectrograph of the McDonald Observatory," by Otto Struve and C. T. Elvey.

"Observations Made with the Nebular Spectrograph of the McDonald Observatory," II, by Otto Struve and C. T. Elvey.

"Observations Made with the Nebular Spectrograph of the McDonald Observatory," III, by Otto Struve, C. T. Elvey, and W. Linke.

No. 10. "The Temperatures of the Extragalactic Nebulae and the Red-Shift Correction," by Jesse L. Greenstein.

No. 11. "The Spectra of Two Reflection Nebulae Studies of Diffuse Nebulãe," by J. L. Greenstein and L. G. Henyey.

No. 12. "The Dynamics of Stellar Systems," I-VIII, by S. Chandrasekhar.

No. 13. "The Ultraviolet Spectra of A and B Stars," by Otto Struve.

No. 14. "The Ultraviolet Spectra of 17 Leporis and P Cygni," by Otto Struve and F. E. Roach.

No. 15. "Spectral Types of Stars of the North Polar Sequence," by Philip C. Keenan.

No. 16. "Magnitudes and Colors of Stars of Large Proper Motion," by Carl K. Seyfert.

No. 17. "Emission Nebulae in Messier 101," by Carl K. Seyfert.

No. 18. "New White Dwarfs, Subdwarfs, and Binary Stars," by G. P. Kuiper.

No. 19. "The Effect of Continuous Balmer Absorption Upon the Equivalent Widths of Stellar Absorption Lines," by Otto Struve and Frances Sherman.

No. 20. "The Distribution of Color in Spirals," by Carl K. Seyfert.

No. 21. "The Spectrum of υ Sagittarii," by Jesse L. Greenstein.

No. 22. "Spectroscopic Observations of Peculiar Stars," by P. Swings and Otto Struve.

No. 23. "Notes on Proper Motion Stars," by G. P. Kuiper.

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